Analysis on factors that influence concentration of PM2.5 expelled in vehicle exhaust in underground parking lots of large shopping centers in Changchun

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Abstract. Our goal is to find out how the passenger number, vehicle type and vehicle displacement influence the PM2.5 concentration in underground parking lots of large shopping centers. To this end, we collected data of PM2.5 concentration in several underground parking lots in CBDs of Changchun. We have some findings from the conducted experiments. First, PM2.5 concentration rises as the number of passengers carried in the vehicle increases. As for vehicle type and displacement, high-displacement sedans and moderate-displacement SUVs contribute most to PM2.5 concentration inside the parking lots, among which vehicles of older age cause even greater pollution, with PM2.5 concentration averaging 208 μg/m³ and 241 μg/m³ respectively. And high-displacement MPVs have greater influence on PM2.5 concentration than low-displacement ones.

1. Introduction

Recently, due to the rapid progress of urbanization, more and more large shopping centers have appeared in large cities and even small cities, which has become the center of many people's daily life. However, these kinds of building groups have complex composition and the traffic status around them is also complicated. When customer flow rises, there will be a surge of traffic flow around the shopping centers and at the entrance of the underground parking lots.

The exhaust gas expelled by the vehicles in the course of operation contains a great amount of pollutant such as CO[1], CO₂, NOx, SO₂, formaldehyde and benzene, which will cause severe pollution to the atmosphere. And it can cause human disease, maybe even cancer, putting a huge threat on the health of everyone[2]. When vehicles enter the underground parking lot at a very high frequency, the pollutant accumulated in that area will reach a very high concentration, which will cause very severe impact on the health of the people in that region. PM2.5 in confined space is able to threat one's life by harming human body's cardiovascular system and respiratory system.

As we can see, cars have become a means of travelling preferred by more and more people, and there are different types of cars for us to choose according to our need, such as sedan, SUV and MPV. As a result, we can see vehicles of various types and displacement appear in the underground parking lots of shopping centers.
So in this paper, we explore how vehicle type, vehicle displacement influence the concentration of pollutant in car exhaust in the underground parking lots of shopping centers, and propose our ideas about pollution control.

2. Method

2.1. Location of experiments
We conduct our experiments in four shopping centers in Changchun (provincial capital of Jilin Province), Wanhao Plaza, Ouya Xinshenghuo, Hongqijie Wanda Plaza and Kuancheng Wanda Plaza. The diversity of size and age of the underground parking lots in these shopping centers ensures the reliability of the collected data and the generality of our experimental results to some extent.

Hongqijie Wanda Plaza is situated in the center of Hongqijie business district, 9 years old, with 33 floors on the ground and 2 floors underground, covering 48,000 square meters, whose gross floor area is about 317,500 square meters. Wanhao Shiji Plaza is situated in where Jingyue Street meets Xincheng Street, 1.5 years old, covering 21,000 square meters, whose gross floor area is about 180,000 square meters. Wanda Kuancheng Plaza is situated in the north square of Changchun Railway Station, 6 years old, providing more than 1200 parking slots underground, covering 102,300 square meters, whose gross floor area is about 441,500 square meters. Ouya Xinshenghuo is a new shopping center which runs only for 3 years, providing 2,000 parking slots in its two-floor underground parking lot (70,000 square meters in total). And the gross floor area of Ouya Xinshenghuo is about 240,000 square meters.

2.2. Experimental settings
We set up our experiment platform in the central parking zone at each floor of the underground parking lots. For each zone, we set four sensors at the corners of the rectangular zone, which are denoted by A, B, C, D in clockwise order as shown in Figure 1. The data sampled in the period in which the target vehicle pass the region are averaged to obtain one data point for this vehicle. First, we experiment with different number of passengers while keeping the engine displacement of the vehicles the same. Then, we vary the vehicle type and vehicle displacement while keeping the number of passengers the same. So we can observe how these three factors influence the pollutant concentration.

In our experiment, we only consider three types of vehicle: sedan, SUV and MPV. The customer flow in the shopping centers is always high, so it's common that two vehicles pass the region consecutively. We avoid this issue by only considering the data collected under situation where the preceding and the following vehicles pass the region before or after a long enough period.

Due to the special nature of large shopping centers and complex composition of indoor air pollution, indoor air quality has attracted more and more attention. Yang et al.[3]conduct experiments and analysis on PM2.5, CO₂ and TVOC in commercial buildings, and demonstrate that the pollutant reaches a hazardous level in the commercial buildings. The 13th Five-Year Plan mentions that improving air quality is vital for our daily life. We find that PM2.5, formaldehyde and CO₂ rank top three among the indoor pollutant through the search in Wanfang Database as well as CNKI. Thus we conduct experiments on PM2.5 in the underground parking lots and analyze the factors that influence the concentration of PM2.5.
2.3. Sensor
We use Honeywell IAQ (shown in Figure 2) for PM2.5 measurement, which is portable and has a well-designed look, and most importantly, is very powerful at indoor air quality measurement. It can measure concentration of PM2.5 in the indoor air, as well as temperature and humidity, at a very high precision, and it is suitable for locations such commercial buildings and community. The data collected by the IAQ are shown in Figure 2.

IAQ can measure PM2.5 of concentration ranging from 100 to 999 μg/m³, with precision of 15%. In the new standard on air quality on the PM2.5 detection website, the level of air quality is divided as follows: 0 μg/m³~35μg/m³, good; 35μg/m³~75μg/m³, moderate; 75μg/m³~115μg/m³, light pollution; 115μg/m³~150μg/m³, moderate pollution; 150μg/m³~250μg/m³, heavy pollution; >250μg/m³ serious pollution.

3. Related work
Liu et al.[4] show that the average concentration of PM2.5 in each day in the underground parking lots of large shopping centers is one millionth, which is higher than that in the outdoor environment. And the concentration of PM2.5 underground appears to be significantly related to the temperature. These findings are helpful for the engineers who work on ventilation design for underground parking lots.

Yang et al.[5] demonstrate that PM2.5 in the underground parking lots is able to cause damage to human's lungs.

S et al.[6] collect 59 samples of indoor underground pollutant across Korea, including 197 samples from subway stations and underground parking lots. They analyze the pollutant in the atmosphere and the concentration of PM2.5 in indoor environment, and reach the conclusion that the concentration of PM2.5 underground is much higher than that in the outdoor environment.

H et al.[7] believe that the pollutants caused by vehicles in the underground parking lot will seriously threaten human health. In their work, the exposure and health risk assessment of fine particles and volatile organic compounds are analyzed. The data in the article show that, depending on the type of ventilation, the concentration of fine particles in underground parking lots is high, inhaled into the body and deposited in all breathing areas, which determines the increased risk of cancer in the underground garage.

Niu et al.[8] show that vehicles, environment, fuel, roads, temperature and the age of the vehicle all have a certain impact on the total emissions of pollutants, of which temperature and vehicle age have the greatest impact on the total emissions of pollutants. And the study finds that the total amount of pollutants emitted by motor vehicles in winter conditions is always higher than that in summer conditions. In terms of vehicle start-up, the total amount of pollutants emitted by the vehicle during cold start is always greater than that of warm start. According to the research results and calculation of the actual pollutant concentration of the underground garage with 6 air changes per hour under the
most unfavorable working conditions, it is found that most of the pollutant concentration exceeds the standard, and the degree of fine particles exceeded the CO concentration, especially PM2.5 far exceeds the national standard.

4. Experiment

4.1. How the number of passengers influences PM2.5 concentration
The relation between passenger number and PM2.5 concentration is visualized in Figure 3. The average PM2.5 concentration is 64 μg/m³ when there is only one passenger in the vehicle, which increases to 82 μg/m³ when three or four passengers are present. In the one-passenger case, 2/3 of samples fall below the national standard value of PM2.5 concentration. In the multiple-passenger case, 1/2 of samples fall below the national standard value of PM2.5 concentration. So we reach the conclusion that the concentration of PM2.5 in the underground parking lots increases as the number of passengers in the vehicle increases.

![Illustration of how the number of passengers influence PM2.5 concentration](image)

Figure 3. Illustration of how the number of passengers influence PM2.5 concentration

4.2. How the engine displacement of a sedan influences PM2.5 concentration
We visualize the concentration of PM2.5 under different settings of displacement in Figure 4. We find that the average concentration of PM2.5 for low-displacement and moderate-displacement sedan is 73 μg/m³ and 76 μg/m³ respectively, which are both around the national standard value. However, the average concentration of PM2.5 for high-displacement sedan is 208 μg/m³, which reaches the heavy pollution level. For low-displacement sedan, 1/2 of samples exceed the national standard value, reaching light pollution. For moderate-displacement sedan, 1/2 of samples exceed the national standard value, reaching light pollution. For high-displacement sedan, 1/10 of samples exceed the national standard value, reaching severe pollution. For high-displacement sedan, 1/10 of samples fall into the concentration range of 115μg/m³~150μg/m³, reaching moderate pollution. 1/2 of samples fall into the concentration range of 150μg/m³~250μg/m³, reaching heavy pollution. Nearly 1/3 of samples exceed the concentration limit of 250 μg/m³, reaching serious pollution.
Due to the abnormality of the data for high-displacement sedan, we further explore the influence of the age of high-displacement sedans on PM2.5 concentration, the results of which are visualized in Figure 5. The high-displacement sedans between ages of 1 to 8 years have PM2.5 concentration of 159 μg/m³ on average, reaching heavy pollution; The high-displacement sedans with age more than 8 years have PM2.5 concentration of 320 μg/m³ on average, reaching serious pollution, which is twice the concentration for sedans between ages of 1 to 8 years. For high-displacement sedans between ages of 1 to 8 years, 1/3 of samples reach moderate pollution and the other 2/3 reach heavy pollution. For high-displacement sedans with age more than 8 years, 1/6 of samples reach heavy pollution and the other 5/6 reach serious pollution.

So we can have some conclusion about how the engine displacement of a sedan influences PM2.5 concentration. The PM2.5 concentration corresponding to low-displacement (less than 1L) sedans is below the national standard. The PM2.5 concentration corresponding to moderate-displacement (1L~3.5L) sedans meets the national standard. The PM2.5 concentration corresponding to high-displacement (more than 3.5L) sedans of older ages greatly exceeds the national standard. The PM2.5 concentration corresponding to high-displacement (more than 3.5L) sedans of younger ages exceeds the national standard, but is lower than that corresponding to sedans of older ages.
4.3. How the engine displacement of a SUV influences PM2.5 concentration

We visualize the concentration of PM2.5 under different settings of displacement in Figure 6. We find that the average concentration of PM2.5 for low-displacement SUV is 39 μg/m³, which is below the national standard value. The average concentration of PM2.5 for moderate-displacement is 213 μg/m³, reaching heavy pollution. The average concentration of PM2.5 for high-displacement SUV is 74 μg/m³. All samples from low-displacement SUV meet the national standard and some samples even achieve "good" air quality. For moderate-displacement SUV, 1/3 of samples fall into the concentration range of 115μg/m³~150μg/m³, reaching moderate pollution, and 1/2 of samples fall into the concentration range of 150μg/m³~250μg/m³, reaching heavy pollution, and 1/3 of samples exceed the concentration limit of 250 μg/m³, reaching serious pollution. For high-displacement SUV, 1/3 of samples fall into the concentration range of 75μg/m³~115μg/m³, reaching light pollution and the rest of samples all meet the national standard.

![Illustration of how the engine displacement of a SUV influences PM2.5 concentration](image)

Figure 6. Illustration of how the engine displacement of a SUV influences PM2.5 concentration

It can be easily observed that the data for moderate-displacement SUV is kind of abnormal. Therefore we further explore the influence of the age of moderate-displacement SUVs on PM2.5 concentration, the results of which are visualized in Figure 7. The moderate-displacement SUVs between ages of 1 to 8 years have PM2.5 concentration of 144 μg/m³ on average, reaching moderate pollution; The moderate-displacement SUVs with age more than 8 years have PM2.5 concentration of 241 μg/m³ on average, reaching heavy pollution, which is 1.6 times the concentration for SUVs between ages of 1 to 8 years. For moderate-displacement SUVs between ages of 1 to 8 years, 5/6 of samples reach moderate pollution and the other 1/6 reach heavy pollution or even worse. For moderate-displacement SUVs with age more than 8 years, 2/3 of samples reach heavy pollution and the other 1/3 reach serious pollution.
Figure 7. Illustration of how the age of a moderate-displacement SUV influences PM2.5 concentration.

So we can have some conclusion about how the engine displacement of a SUV influences PM2.5 concentration. The PM2.5 concentration corresponding to low-displacement (less than 2L) SUVs is below the national standard. The PM2.5 concentration corresponding to moderate-displacement (2L~4L) SUV of older ages greatly exceeds the national standard. The PM2.5 concentration corresponding to moderate-displacement (2L~4L) SUV of younger ages exceeds the national standard, but is lower than that corresponding to SUV of older ages. The PM2.5 concentration corresponding to high-displacement (more than 4L) SUVs meets the national standard.

4.4. How the engine displacement of a MPV influences PM2.5 concentration

We visualize the concentration of PM2.5 under different settings of displacement in Figure 8. We find that the average concentration of PM2.5 for low-displacement MPV is 38 μg/m³, achieving "moderate" air quality. The average concentration of PM2.5 for high-displacement MPV is 73 μg/m³, which is around the national standard value. All samples from low-displacement MPV meet the national standard and some samples even achieve "good" air quality. For high-displacement MPV, 1/2 of samples fall into the concentration range of 75μg/m³~115μg/m³, reaching light pollution and the rest of samples all meet the national standard.

Figure 8. Illustration of how the engine displacement of a MPV influences PM2.5 concentration.
So we can have some conclusion about how the engine displacement of a MPV influences PM2.5 concentration. The PM2.5 concentration corresponding to low-displacement (less than 2.5L) SUVs meets the national standard. The PM2.5 concentration corresponding to high-displacement (more than 2.5L) SUVs is around the national standard.

5. Conclusion
From the experimental results, we can draw a conclusion that the concentration of PM2.5 released from the exhaust gas of vehicles is related to the number of passengers carried in a vehicle as well as the engine displacement of the vehicle. First, PM2.5 concentration increases as the number of passengers increases. Second, sedans of displacement more than 3.5L and SUV of displacement between 2L to 4L contribute higher level of pollution. And high-displacement sedans of older age and moderate-displacement SUVs of older age cause even more serious pollution. For MPV, high-displacement ones have more significant influence on air quality than low-displacement ones. So the engine displacement is not the only factor that influences the PM2.5 concentration caused by the vehicle. For example, the age of the vehicle should also be considered. When designing vehicles, we should consider the burden that high engine displacement brings to everyone's daily life. The service life of vehicles should also be properly restricted to reduce emission of exhaust gas.

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