IOP Conf. Series: Earth and Environmental Science **121** (2018) 032034 doi:10.1088/1755-1315/121/3/032034

Simulation of concentration distribution of urban particles under wind

Yanghou Chen[1,3] and Hangsheng Yang[2]

[1] Department of mechanical and electrical engineering, mechanical and vehicle engineering college, WeiFang University;
[2] School of materials science and engineering, Zhejiang University

[3] chenyanghou@126.com

Abstract. The concentration of particulate matter in the air is too high, which seriously affects people's health. The concentration of particles in densely populated towns is also high. Understanding the distribution of particles in the air helps to remove them passively. The concentration distribution of particles in urban streets is simulated by using the FLUENT software. The simulation analysis based on Discrete Phase Modelling (DPM) of FLUENT. Simulation results show that the distribution of the particles is caused by different layout of buildings. And it is pointed out that in the windward area of the building and the leeward sides of the high-rise building are the areas with high concentration of particles. Understanding the concentration of particles in different areas is also helpful for people to avoid and reduce the concentration of particles in high concentration areas.

1. Introduction

Due to the development of the economy, especially in northern China, fog and haze is getting worse and worse. In the absence of wind or windy weather, the accumulation of particulate matter is particularly serious. Jin, S, Guo et al. discussed the influence of street trees on the distribution of PM2.5 in towns[1]. Prada, Y, Huang, S. et al. Studied the effects of different shapes of roofs on the distribution of wind and particles in the streets[2, 3]. Eeftens , M. et al. Studied the spatial distribution of particulate matter due to the emission of NO_2[4]. Karra , S., et al. studied the pollution of particulate matter caused by traffic jams in the streets[5]. Ziskind, G. et al. reviewed the study of particle resuspension in turbulent flow[6]. Domestic Qiang N studies the control and management of urban air quality[7]. In addition to strict control of exhaust emissions and dust removal technology upgrade, it is feasible to remove the atmospheric particulate matter passively. China now has some patents and measures for atmospheric haze removal. Even if its validity needs further study and verification, it is significant to study the particle concentration in the urban street. Particle removal may be better at higher particle concentrations. Understanding the concentration of particles in different areas is also helpful for people to avoid and reduce the concentration of particles in high concentration areas.In this paper, the distributions of particle concentration due to wind transport and the different distribution of street buildings are studied.Depending on the concentration of the particles, it is possible to find the characteristics of the particles that can be aggregated to guide the accumulation of particles so that they can be removed effectively.

2. Numerical study of three-dimensional model flow field

2.1. Modeling of three-dimensional model flow field
Numerical simulation of the concentration of particulate matter under the condition of breeze is carried out in the urban street. The three-dimensional model and configuration of the building is shown in figure 1. The range of length * height* width is 450(x) m * 80(y) m * 220(z) m. The higher building height is 60 meters. Low building height is 30 meters. The street width at A, B, C point is 36 meters. And that of D point is 18 meters. Particles and air flow from left to right.

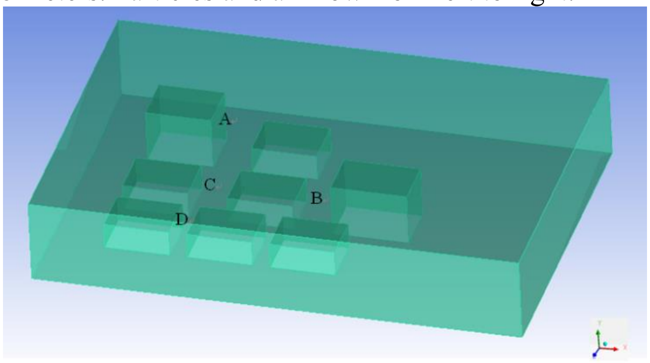

Figure 1. Three-dimensional model flow field.

2.2. Modeling of DPM
ANSYS-FLUENT is popular computational fluid dynamics software, which is widely used in the simulation of single-phase and multiphase flow and particle. The Discrete Phase Modelling (DPM) can not only be used to deal with the particles in the stable flow field, but also can be used to calculate the particle coupling in the transient flow field. In this paper, the DPM model is used to simulate and analyze the building and street layout of the three dimensional urban street under the condition of low wind speed. RNG k- epsilon model is used for the initial flow field. The velocity field is evaluated by solving the Reynolds Average Navier-Stokes (RANS) by the software. Trajectory of particle is calculated by integrating the force balance equation[3, 6, 8, 9]:

$$\frac{du_i^p}{dt} = F_D\left(u_i - u_i^p\right) + g_i(\rho_p - \rho)/\rho_p + F_i/\rho_p \tag{1}$$

In Formula 1, F_D for drag force, $g_i$for Gravity force, Fi for Additional forces: such as Brownian motion, Saffman lift, Thermophoretic and so on.

2.3. Force of particles:
The interaction between the particles, the particles and the surrounding fluid will continue in the gas-solid two-phase flow field. The actual force of particles in the flow field can be calculated according to Newton's second law:

$$m_p \frac{d\mu_p}{dt} = \Sigma F \tag{2}$$

In Formula 2, m_p for particle mass quantity, ΣF for resultant force of particles. The force of the particles is divided into the following three: 1. longitudinal force along the direction of relative motion, such as force of resistance and Basset. 2. Lateral force in the direction of vertical relative motion, such as force of Magnus and Saffman. 3. The fluid and particle relative motion without relevance force, such as Brownian diffusion force. On the basis of Cen Kefa[8], in general, the magnitude of the pressure gradient force and Saffman force is very low. Even in the non isothermal flow field, the Magnus force of the particles in the PM10 particle size is in the same order of magnitude as the gravity. The

IOP Conf. Series: Earth and Environmental Science **121** (2018) 032034 doi:10.1088/1755-1315/121/3/032034

simulation calculated results also show that the pressure gradient force and virtual mass force have little effect on the results.

3. Simulation results analysis

The simulations mainly show the concentration of particles at different locations. Figure 2 shows the location of the selected simulation. In addition to the points shown in figure 1, the locations of the intercepted linear spatial regions are also shown. They correspond to each point of the A, B, C and D, and also have the coordinates of the corresponding diagrams. The mass concentration of the particles in the corresponding linear region is shown in figures blow[9].

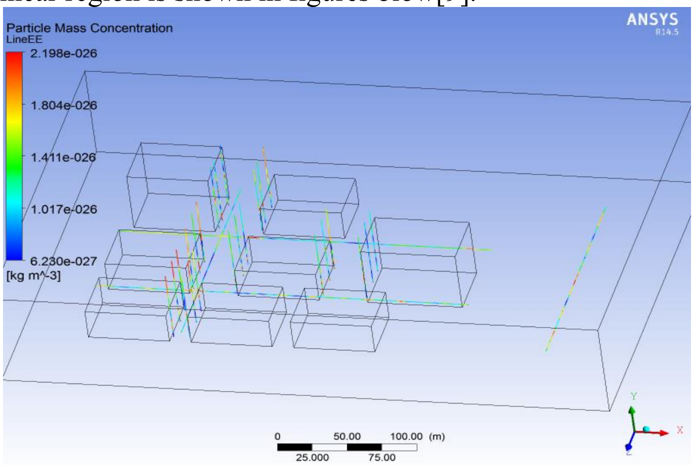

Figure 2. Particle mass concentration of different selected lines..

In figure 2, different colour changes on selected line areas show significant variations in particle concentrations at different locations within the region. This can be clearly demonstrated by particle mass concentration profiles figure 3 and velocity profile figure 4 of the section at the Z=-60m position.

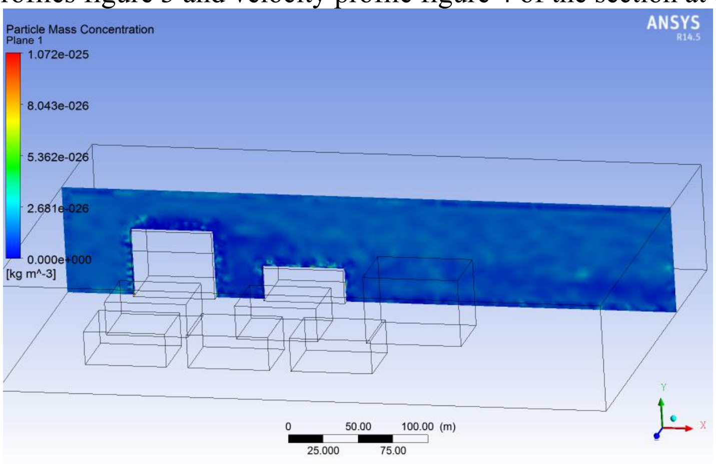

Figure 3. Particle mass concentration of plane 1(Z=-60m).

Figure 3 shows the mass concentration distribution of the particles at the Z=-60m position profile. As we can see from the figure, the concentration of the particles in the lee side of the building is relatively low relative to the windward side. For different height areas near the building, there are several distribution points with higher concentration. For different building height and the distance between the streets, the influence of the concentration disturbed flow in the corresponding area will also be different. The velocity contours of this section in figure 4 can also illustrate the problem on the other hand.

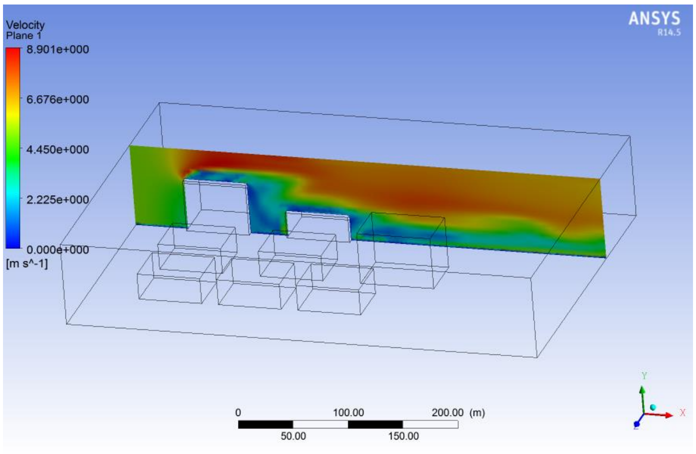

Figure 4. Velocity contours of velocity (Z=-60m).

The layout of the buildings leads to changes in the flow field, which results in uneven distribution of particles in the air. In figure 5 and figure 6 are the mass concentration and velocity contours of particles corresponding to figure 3 and figure 4 of the Z=70m position, respectively. In the figure 5 and figure 6 (plane 3), there are three buildings, and the windward side of the first building height is 30 meters high. In figure 3 and figure 4, the height of the first building on plane 1 is 60 meters.

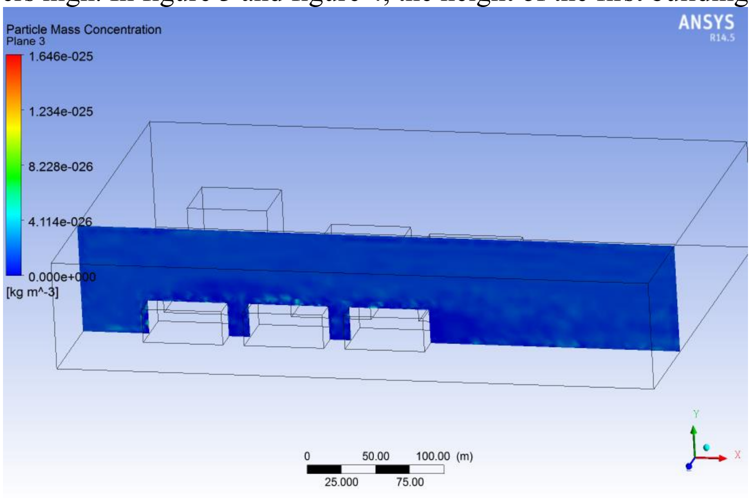

Figure 5. Comparison of particle concentration of plane 3(Z=70m).

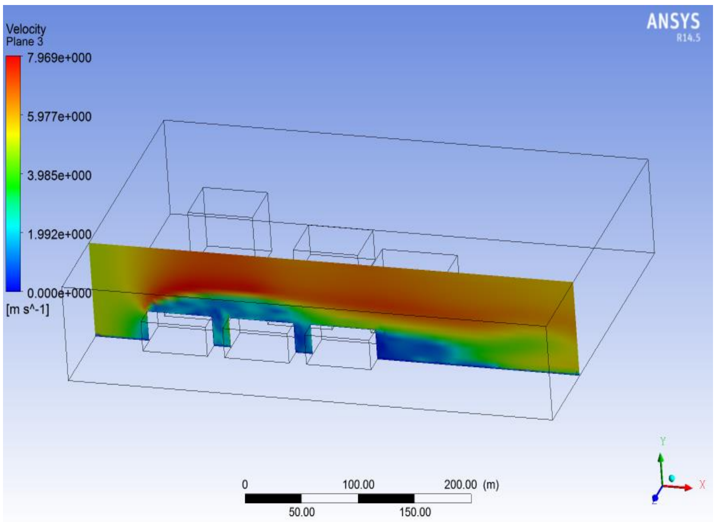

Figure 6. Comparison contours of velocity of plane 3(Z=70m)

Both the height of the building and the direction of its inflow are covered by other buildings and so on, which can influence its flow field. The mass concentration distribution of particles under the action of various forces is mainly affected by the velocity field. In the post processing of the simulation results, the velocity vectors in different profiles can be observed by slicing different slices of plane in the simulated region. Figure 7 shows the contours of DPM concentration (a) and contours of velocity magnitude (b) field of the Z axis (Z=-45m) and the Y axis (Y=10m). The section can be intercepted at any desired position as required.

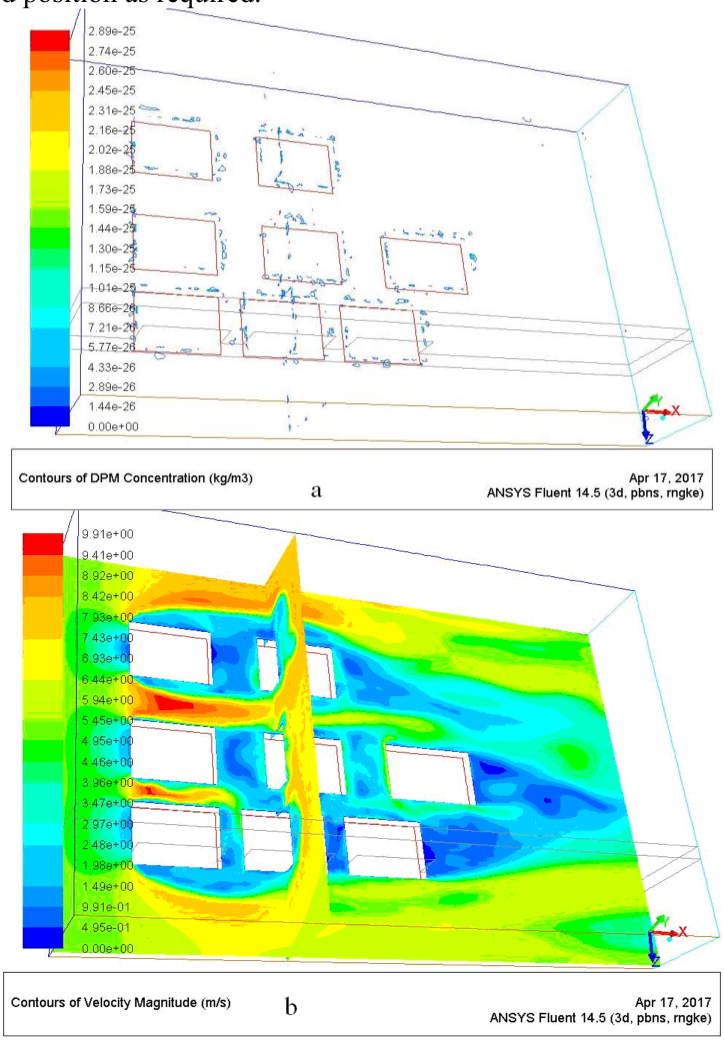

Figure 7. Contours of DPM concentration (a) and contours of velocity magnitude (b).

Not only the cross section, but also the linear region can be sampled in the simulation area. Figure 2 is a simulation result of a linear region taken by this simulation analysis. Graphical representation can be used, or numerical analysis can be done. Figure 8 is the data on several curves of the lee side of the building in the A point region. As can be seen from the diagram, the mass concentration of particles fluctuates greatly due to the different height directions. For the same height position, the projection position of the point on the horizontal plane is different, and the mass concentration of the particles is also different, especially at the height of 50 meters. The horizontal point at Z=-90m is obviously higher than the other two points. At a height of 30 meters, the mass concentration of particulate matter at three points has reached a higher level.

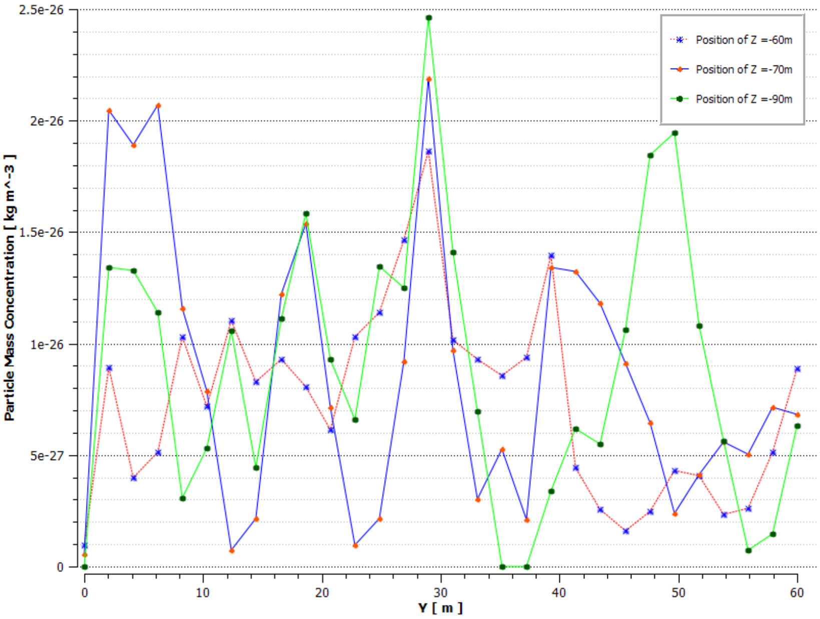

Figure 8. Particlemass of concentration.

Figure 9 is the data on several curves of the windward side of the building in the A point region. Figure 8 and figure 9 shows that the mass concentration of three point particles investigated in figure 9 is obviously different from that in figure 8. The concentration changes in figure 8 and figure 9 show great randomness. The mass concentration of the particles in figure 9 is relatively small relative to the mass concentration changes of the particles in figure 8 due to the shielding of the higher buildings in front.

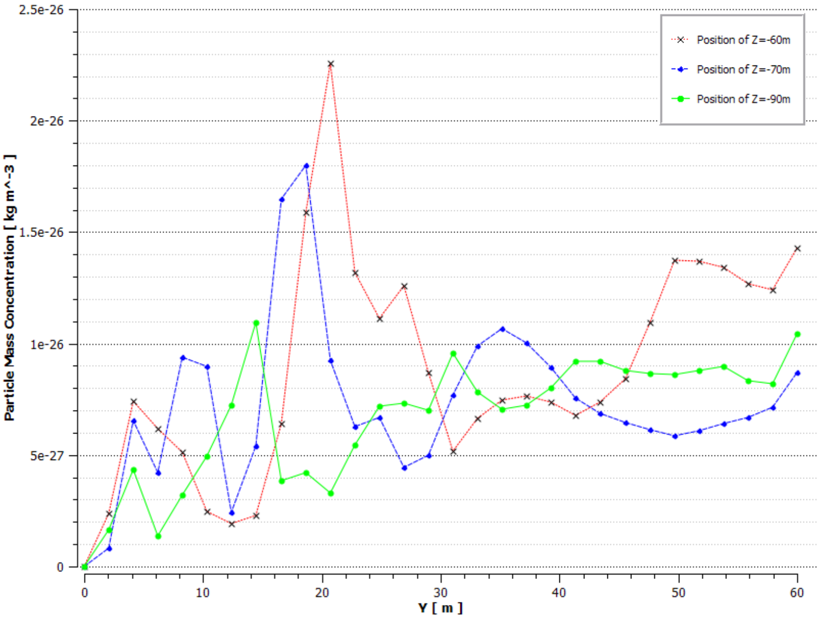

Figure 9. Particle mass of concentration.

The main observation is that the concentration of a point on the horizontal surface changes in height. Figure 10 is a change in the mass concentration of the particles in the linear region of the two axial directions of the Z in figure 2.

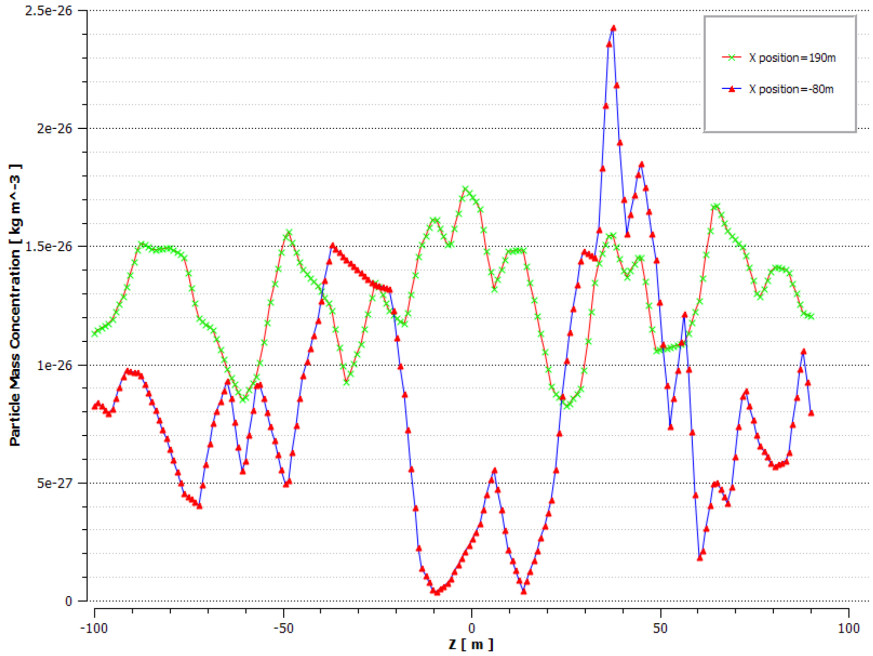

Figure 10. Particle mass of concentration.

As seen in figure 10, the fluctuations of the linear region values observed in the X=-80m position are larger than those in the linear region at X=190m. This is because the former is located in a more complex area of the building layout. The latter is located in a relatively open area. Due to the influence of the surrounding buildings, the values of two linear regions in figure 11 also showed great randomness.

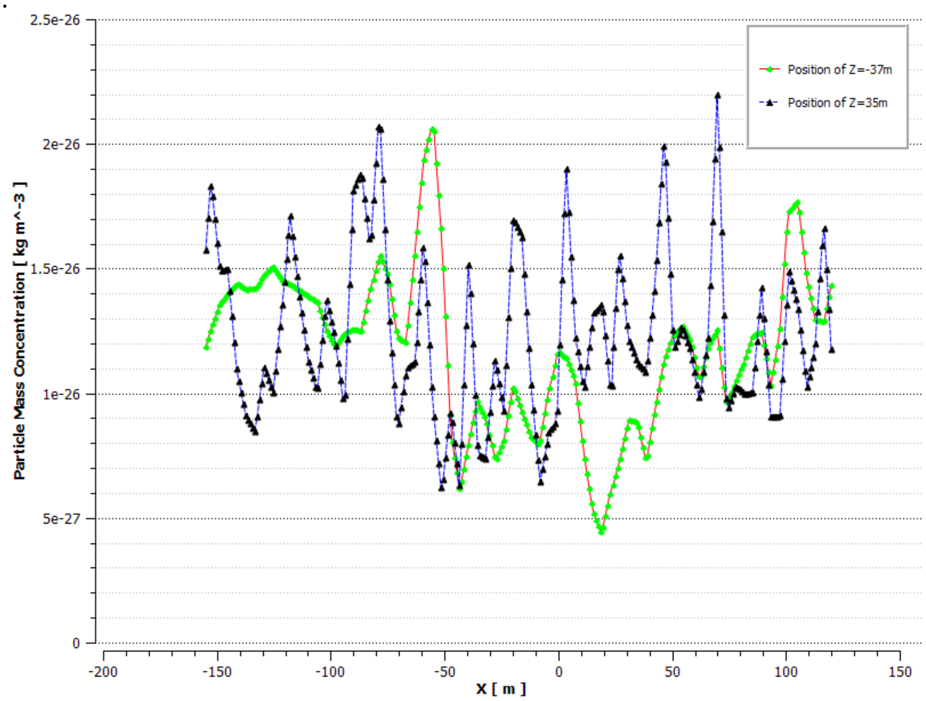

Figure 11. Particle mass of concentration.

4. Discussion and conclusions

The simulation uses low density single particle size to study concentration distribution. The distribution of particles with different sizes and densities in the air is not considered. In this paper, a tetrahedron mesh model is used to segment the model. The inlet velocity is three meters per second, and the outlet is outflow. The incident particle size is micron series. The fly ash material provided by FLUENT software is used and the density of ash has not changed. The particles enter the flow field at an hourly mass of 200 grams. From the above analysis we can see that the distribution of urban streets and buildings affect the concentration of particles in the air. The variation of flow field results in the aggregation and dispersion of particles. It is difficult to determine the exact value of particle concentration at a given point by the given numerical curve. The concentration of a given area can be roughly determined by comparing the concentration of a contour with the concentration of a particle. In addition to the change of its location and height, the layout and shape of the building will also affect its concentration. Because of the disturbance of buildings, the concentration of particles is very random when they do not take account of local points and divergent sources. However, there is still some regularity in its distribution. As we can see from figure 8, the concentrations of the studied points (Y=30 meter) have reached higher values, and areas similar to these are areas of interest for research. A suitable flow field can be selected to make the particles concentrate in one place, so that a small high-voltage electrostatic dust collecting device can be considered in this area for dust removal.
Therefore, in addition to investigating the concentration distribution of particles, this paper also provides a method for improving passive removal of particulates. That is, in a suitable area, the flow field is changed so that the particles are properly gathered so as to remove dust in the high particle concentration area.

Acknowledgment
We would like to extend our deepest thanks to Prof. Yang hangsheng and his research team. This work was supported by the natural science foundation of Shandong Province (ZR2014DL010), and Project of domestic visiting scholars of young teachers of higher education institutions in Shandong Province.

References

[1] Jin S, Guo J, Wheeler S, et a1 Evaluation of impacts of trees on PM25 dispersion in urban streets *Atmospheric Environment*
[2] Parda Y, He WR, Zhou ZH, et alA numerical study on airflow and particle dispersion within an urbn street canyon with different wedge-shaped roofs *Advanced Materials Research*
[3] Huang, S, LiQS, XuS2007 Numerical evaluation of wind effects on a tall steel building by CFD *Journal of Constructional Steel Research*
[4] Eeftens, M, Tsai, M Y, et al Spatial variation of PM 25, PM 10, PM 25 absorbance and PM coarse concentrations between and within 20 European study areas and the relationship with NO2–Results of the ESCAPE project *Atmospheric Environment*
[5] Karra S, Malki-Epshtein L et al The Dispersion of Traffic Related Pollutants Across a Non-Homogeneous Street Canyon *Procedia Environmental Sciences*
[6] Ziskind, G, Fichman, M, & Gutfinger, C Resuspension of particulates from surfaces to turbulent flows—review and analysis *Journal of Aerosol Science*
[7] Qiang N Urban air quality control and management *Beijing Science Press*(in Chinese)
[8] CEN Kefa, Fan Jianren 1990Engineering gas-solid multiphase flow theory and calculation of Hangzhou: *Zhejiang University Press* (In Chinese)
[9] Fluent Inc, FLUENT 6.2.1 User Guide, 2004