Effect of active control of indoor gas flow field on the efficiency of air purifier

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Abstract. In this paper, it is proposed to use electric fan to actively control the indoor gas flow field to improve the ability of an air purifier to capture PM2.5 and other fine particles. For this purpose, an indoor physical model formed by a room, an air purifier and an electric fan is established and the simulation software Fluent is used to simulate the gas flow field distribution and PM2.5 particle tracking. The control method of the electric fan based on periodic rectangular wave is adopted to control and maintain the steady and conducive indoor gas flow field distribution for gathering particle pollutants into the air purifier’s inlet. The simulation results show that the active control method of gas flow field can improve the purification speed and effectiveness of air purifier, and the simulation results are verified by actual test of the purification process of PM2.5 particles in an enclosed room. It provides an economical, practical and effective method to improve indoor air quality.

1. Introduction
Over the past few decades the haze pollution caused by the rapid development of China’s economy has become a serious environmental problem, which threatens the living environment and physical health of human [1-4]. The source of haze varies, such as automobile exhaust, industrial emissions, construction dust, waste incineration and even volcano. Haze weather is usually a mixture of multiple sources of pollution with different degree of effect in various regions. Sulfur dioxide, nitrogen oxides and particulate matter are three main components of haze, the first two of which are gaseous pollutants and the last particulate matter is mainly to blame for aggravating haze. At present, the particulate matter PM2.5 monitored in China is also pollutant particles whose diameter is less than or equal to 2.5 micron in aerodynamics. Sustained frequent, contiguous and increasingly serious haze makes urban air pollution one of the public’s most concerns. However, the governance of haze is not a simple and overnight thing. It is not only the task of the environmental protection departments, but also the responsibility of the local and central government to establish as soon as possible the general rules and implementation details for prevention and control of particulate pollution, and it has a long way to go. As a result, the air purifier has become the most important means to solve indoor air pollution.

The main technical indexes of air purifier in market include fan air volume, purification efficiency (CADR), energy efficiency ratio and safety performance, according to which user can roughly select suitable products and models. The reading of PM2.5 on the air purifier reflects its purification effect, but it is confined to nearby location and can't reflect the situation of the whole room. In fact, the purification effect of the air purifier is no only associated with the capture efficiency, but also the
portion of indoor particulate matter entering the purifier with circulating wind, that is, air quality improvement indoors is not only related to the air purifier performance but also the working conditions [5].

Many scholars have conducted the research on suspended particles. Corner et al. obtained the particle deposition rate formula through the study of aerosol deposition in rectangular box [6]. Shimada et al. considered the inertia effect of particles [7]. Nazaroff et al. considered the heat transfer effect of particles [8]. Lu et al. applied Lagrange method to simulate the distribution of particles in two-dimensional ventilation room, and successfully studied the change of average concentration of different particle size [9]. Zhang compared the simulation results of particle spread and diffusion of Euler and Lagrange method, and the results show that Lagrange is better than Euler in the simulation of transient contaminant propagation [10]. Murakami et al. measured the particle concentration distribution of 0.31um and 4.5um respectively in clean room with ceiling ventilation [11].

With the development of computer, numerical simulation of air distribution by computational fluid dynamics came into being. By solving the mass, momentum, energy, gas composition mass conservation equation and particle motion equation, the parameters of wind speed, temperature, relative humidity, pollutant concentration and air age were obtained in different indoor locations so as to analyze and evaluate the ventilation efficiency, thermal comfort and pollutant removal efficiency etc [12]. In early 1970s, the Danish scientist P.V. Nielsen simulated the indoor air flow, and for the first time CFD was applied in air-conditioning engineering, together with the joint use of k-ε model and flow function and vortex formula to solve closed two-dimensional flow equation [13]. Gosman proposed Prescribe Velocity Method for inlet boundary conditions [14]. Reinartz and Renz calculated in detail the velocity and temperature distribution in the room with annular diffuser, and simulated the diffuser [15]. Emmerich et al. applied large eddy simulation (LES) in the research of the hot air flow and smoke spread in three-dimensional room [16]. Many scholars use CFD numerical simulation method to study the influence of indoor air flow field on the spread of pollutant. Lee et al. analyzed the influence of indoor layout and source location on indoor pollutant concentration distribution and ventilation efficiency through numerical simulation and experiment under the condition of upper air supply [17]. Li and Xu studied the effect of fresh air and location of air outlet on indoor concentration [18]. Zhang compared the air velocity, temperature and gas pollutants concentration distribution of floor air supply systems under different operating conditions [19]. Meng established a model of air purifier, with the use of Fluent software on the numerical simulation and simulation study of the internal flow field of air purifier, which was a expansion design of original purifier [20]. Yin studied the effects of different air surface velocities on the particle concentration of 1um, 2.5um, and 10um in human respiratory area in the case of closed window [5]. Zhou used the Fluent software to simulate the air distribution of air-conditioning room, where implementable k-ε model combined with wall function were applied to establish a three-dimensional turbulent mathematical model of velocity and temperature field of air-conditioning room [6]. Particle trajectory model was also used to simulate the trajectory and concentration distribution of particulate pollutants in air-conditioning room under different airflow, and the influence of particle size on concentration distribution was analyzed.

In summary, the study of particulate matter, gas flow filed and the effect of gas flow filed on pollutant transmission shows that the purification effect of air purifier is affected by the size and shape of the room, the placement of the air purifier, outlet velocity, and the direction of inlet and outlet, etc. However, the method of improving the pollutant removal efficiency of air purifier by actively changing the gas flow field in the room has not been found. Therefore, the method of improving the purification efficiency of air purifier by actively controlling indoor gas flow field distribution to increase the portion of indoor particulate matter such as PM2.5 entering the purifier with circulating wind is proposed in this paper, which is verified by simulation and actual experiments.

2. Numerical simulation

The trajectory of PM2.5 and other particles indoors is mainly completed through physical modeling, meshing, simulation parameter settings and solution process.
2.1. Mathematical model

Due to the fact that the volume fraction of PM2.5 and other particles in the atmosphere should be less than 10-20 percent, the simulation is in accordance with the sparse phase, which can be calculated through DPM model in the Fluent software, ignoring the interaction among particles in two-phase flow. The DPM model in Fluent follows Euler-Lagrange method, calculates the gas flow filed in the continuous phase, and then calculates the trajectory of discrete phase particles in the continuous phase flow field. Coupling calculation of continuous phase and discrete phase is proceeded with taking into consideration the interaction between the two phases. Because of the infinite suspension state of the simulation particles in the continuous phase, the unsteady DPM model is used to solve the problem.

2.1.1. Governing equation of gas flow. In order to numerically simulate the interior space, the governing equations which include mass conservation, momentum conservation, energy conservation, turbulence model, etc. must be established to accurately describe the law of air flow.

Mass conservation equation:
\[
\frac{\partial \rho}{\partial t} + \frac{\partial (\rho \mathbf{u})}{\partial x} + \frac{\partial (\rho \mathbf{v})}{\partial y} + \frac{\partial (\rho \mathbf{w})}{\partial z} = 0
\]
(1)

In the equation, \(\rho\) is the air density, \(t\) is the time, \(u\), \(v\), and \(w\) are components of velocity vector in \(x\), \(y\), and \(z\) directions respectively, which states that the mass increase of micro fluid unit equals to the net mass inflow into the micro unit.

Momentum conservation equation:
\[
\begin{align*}
\rho \frac{\partial \mathbf{u}}{\partial t} + \rho \mathbf{u} \cdot \nabla \mathbf{u} &= -\nabla P + \rho \mathbf{g} + \tau \quad \text{(pressure force, gravity, viscous stress)}
\end{align*}
\]
(2)

In the equation, \(U\) is resultant velocity, \(P\) is pressure on micro fluid unit, \(\tau_{xx}, \tau_{xy}, \tau_{xz}\), etc. are components of viscous stress on the surface of micro unit due to molecular viscosity, \(-\rho g\) is gravity in the direction of \(z\). The equation can be expressed as: the change rate of flow momentum in micro unit to time is equal to the sum of all kinds of eternal forces acting on the micro unit.

Energy conservation equation:
\[
\frac{\partial \mathbf{U}}{\partial t} + \nabla \cdot (\mathbf{U} \mathbf{U}) = -\nabla \cdot (\rho \mathbf{g}) + \nabla \cdot (\tau \mathbf{U}) + \rho \mathbf{g}
\]
(3)

Turbulence equation:

In this paper, RNG \(k-\varepsilon\) model is used in turbulent numerical simulation to better handle the flow with high strain rate and large curvature of flow line.

2.1.2. Particle motion equation. According to Newton’s law of motion and force of particles, the equation is established as follows.
\[
\frac{d \mathbf{u}_p}{dt} = F_D(u - u_p) + g_x - g_x \frac{\rho}{\rho_p} + F_x
\]
(4)

In the equation, \(F_D(u - u_p)\) is drag resistance of unit mass of particle in the \(x\) direction, resistance coefficient \(F_D = \frac{18 \mu}{\rho_p d_p^2} C_p R_e\), \(u\) is gas phase velocity, \(u_p\) is particle velocity, \(\mu\) is fluid dynamic
viscosity, $\rho$ is fluid density, $\rho_p$ is particle density, $d_p$ is particle diameter, and relative Reynolds number is $R_e = \frac{\rho d_p |u_p - u|}{\mu}$.

$g_x$ is the component of gravity of unit mass particle in the x direction.

$g_x \frac{\rho}{\rho_p}$ is the component of buoyancy of unit mass particle in the x direction.

$F_x$ is component of additional force in the x direction, such as thermophoresis, Basset force, Saffman force and additional force due to particle rotation. The effects of additional forces are not considered in this paper.

Particle trajectory equation:

$$\frac{dx}{dt} = u_p$$ (5)

2.2. Physical model

This paper takes a 5-storey, south-facing room in Beijing as an example for numerical simulation. The size of the room is 4.9m x 3m x 2.8m (length x width x height), with a window facing the south and the front door in the east, and there is an air purifier and an electric fan in the room. The room model built by Gambit modeling software is shown in figure 1. The air purifier, size of 0.432m x 0.268m x 0.638m (length x width x height), is placed against the wall in the middle of south. Purifier-room-out is the inlet of the air purifier, whose size is 0.38m x 0.24m (length x wide). Purifier-room-in is the outlet of the air purifier, with size of 0.19m x 0.085m (length x wide). The circular fan with a diameter of 0.4m is placed against the wall in the middle of north, facing directly the inlet of the air purifier. The effect of electric fan on gas flow field is expressed by the lumped parameter model of electric fan. Here, a circular surface Fan-face with the sickness of infinite thin and the diameter of 0.4m is used to simulate an electric fan. There are certain relationships between the pressure difference $\Delta P$ of both sides of Fan-face and the air velocity flowing through the fan.

In the model, purifier-room-in is set as the boundary condition of velocity inlet, purifier-room-out is set as the boundary condition of outflow, and Fan-face is set as the boundary condition of interface. The Fan-face divides the room into two sections, setting the other faces in the room as actual walls.

Make the following assumptions in simulation process:

- Ignore the influence of the heat dissipation of household appliances, lighting equipment, personnel, etc. on pollutant diffusion in the room.
- Ignore the infiltration air volume of the front door and window gap, etc. regarding the room with closed doors and windows as a closed space.
2.3. Meshing
The meshing of the room model is carried out with Tet/Hybrid grid cell and TGRID grid type. The total grid number of the flow field in the whole room is 214156.

2.4. Simulation parameter settings
Whether the numerical simulation parameters and the boundary condition settings accord with the reality or not determines the accuracy of the numerical simulation results of Fluent. Therefore, it is necessary to reasonably simplify the boundary condition and set the parameters for accurately calculating the governing equations as shown in Table 1.

| Table 1. Simulation parameter settings. |
|---------------------------------------|
| Space       | 3D                  |
| Time        | Steady              |
| Model       | Viscous             |
|             | RNG k-epsilon turbulence model |
| Discrete Phase Model | Unsteady           |
| Wall Treatment | Standard Wall Functions |
| Solver      | Pressure Based      |
| Formulation | Implicit            |
| Velocity Formulation | Absolute           |
| Pressure-Velocity Coupling | SIMPLE           |
| Pressure Discretization Scheme    | Standard          |
| Momentum    | Second Order Upwind Turbulent |
| Kinetic Energy | Second Order Upwind   |
| Material Properties | PM2.5 Density | 783 kg/m3 |
| Air (fluid) Density                 | 1.225 kg/m3      |
| Hypothesis                             |
| Purifier efficiency of 100%, no PM2.5 particles in its outlet |
| Airflow is regarded as incompressible gas in the simulation process |
| The gravity settling velocity of particles is determined by Stokes equation |
| Indoor gas is regarded as constant physical fluid, and its density, viscosity and other parameters remain unchanged, meeting the Boussinesq hypothesis |

3. Simulation results and analysis
3.1. Characteristics of airflow distribution in the room
The purifier-room-in boundary condition of the air purifier is set to three different surface velocity of 0.05 m/s, 0.5 m/s and 1.5 m/s, and the pressure difference $\Delta P$ of electric fan is set to two cases of 0 and 100 respectively. Figure 2 shows the airflow streamlines of the air purifier outlet when the air purifier and the fan works for 300s in different circumstances. Figure 3 shows the velocity contour of gas flow field in $y=0$ plane.
It can be seen from Figure 2(a), 2(b), 2(c) and Figure 3(a), 3(b), 3(c) that when the purifier surface velocity is 0.2 m/s, fresh air that comes out from the purifier falls rapidly, easily leading to the short circuit of fresh air, which affects the purification effect. The situation improves when the surface velocity is 0.5 m/s. Fresh air can reach the top of the room and be delivered to the rest of the room when the purifier has a surface velocity of 1 m/s. It can be seen from Figure 2(d), 2(e), 2(f) and Figure 3(d), 3(e), 3(f) that when the fan pressure difference $\Delta P$ equals 100, fresh air can be transported to the rest of the room even if the surface velocity is only 0.2 m/s, thus improving the purification effect. It can be seen from the velocity diagram of gas flow field shown in Figure 3(d), 3(e) and 3(f) that when the fan pressure difference $\Delta P$ equals 100, the vortex area is formed, therefore, easily lead to the suspension of indoor PM2.5 and other particulate pollutants in this region.

3.2. Effect of electric fan on capture performance of PM2.5 particulate pollutants in a closed room

At the beginning of simulations, 9992 PM2.5 particles were evenly distributed in the room, the purifier-room-in boundary condition of the air purifier was set to 1 m/s (surface velocity), and the fan pressure difference were $\Delta P=0$, $\Delta P=5$, $\Delta P=50$, $\Delta P=100$ and $\Delta P=150$, under which condition the performance of the air purifier capturing PM2.5 particulate pollutants was simulated. Figure 4 shows the decrease of the PM2.5 particle number in the room with time under different working conditions of the electric fan.
Figure 4. Velocity contour of gas flow field when the air purifier and the fan works in different circumstances: (a) purifier surface velocity 0.2 m/s, pressure difference $\Delta P=0$, (b) purifier surface velocity 0.5 m/s, pressure difference $\Delta P=0$, (c) purifier surface velocity 1 m/s, pressure difference $\Delta P=0$, (d) purifier surface velocity 0.2 m/s, pressure difference $\Delta P=100$, (e) purifier surface velocity 0.5 m/s, pressure difference $\Delta P=100$, (f) purifier surface velocity 1 m/s, pressure difference $\Delta P=100$.

When the electric fan was not working ($\Delta P=0$), the air purifier captured 557 PM2.5 particulate pollutants at 150 seconds, remaining 94.2%. The capture rate gradually increased when $\Delta P = 5$, $\Delta P = 50$, $\Delta P = 100$, and $\Delta P = 150$, remaining 90.4%, 84.4%, 82.7%, 80.7% respectively.

It can be seen from Figure 5 and Figure 6 that when the electric fan was not working ($\Delta P=0$), the flow field in the room was symmetrical, and the fresh air was transported to most of the room. With the increase of $\Delta P$, the gas flow field in the room appeared asymmetrical, and there were multiple eddy currents, fresh air can only be transported to part of the room and the capture rate of PM2.5 particulate pollutants increased slowly.

Figure 5. Airflow streamlines at the outlet of the air purifier and at the fan interface when the fan works for 150s under different pressure differences: (a)$\Delta P=0$, (b)$\Delta P=5$, (c)$\Delta P=50$, (d)$\Delta P=100$, (e)$\Delta P=150$. 

Figure 6. Pressure jump of the fan: $\Delta P=0$ (pascal), $\Delta P=5$ (pascal), $\Delta P=50$ (pascal), $\Delta P=100$ (pascal), $\Delta P=150$ (pascal).
3.3. Active control of gas flow field to improve the capture rate of PM2.5 particles

In order to investigate the effect of active flow control on the PM2.5 particulate capture rate, four simulation conditions were set for the fan (Figure 7).

- Point 1: Fan does not work, the fan pressure difference $\Delta P = 0$.
- Point 2: $\Delta P = 100$.
- Point 3: When $t<310s$, $\Delta P=100$, When $t>310s$, $\Delta P = 0$.
- Point 4: Using periodic rectangular wave control method, that is, $\Delta P=100$ and $\Delta P=0$ are alternately presented with a certain duty cycle.

The purifier-room-in boundary condition of the air purifier was set to 1m / s. At the beginning of simulations, 9992 PM2.5 particles were evenly distributed in the room.

As can be seen from Figure 7, in the first case (Point 1), the air purifier captured 1941 PM2.5 particulate pollutants at 530 seconds, remaining 80.6%. In the second case (Point 2), the air purifier captured 2616 PM2.5 pollutants at 530 seconds, remaining 73.8%. Obviously, the active control of gas flow field can improve the effectiveness of the air purifier for reducing indoor PM2.5 particulate pollutants level. In the third case (Point 3), the fan pressure difference was changed from $\Delta P = 100$ to $\Delta P = 0$ after 310 seconds. At 530 seconds, the air purifier captured 2863 PM2.5 particulate pollutants, remaining 71.3%. Although the fans stopped working, the captured number of PM2.5 particulate pollutants increased in comparison with the second condition in which the electric fan was operating at all times. The main reason is that the asymmetry of the gas flow field and eddy current phenomenon caused by the fan is not conducive to the capture of particulate pollutants. In the fourth case (Point 4), the active control method of periodic rectangular wave was adopted, where $\Delta P = 100$ and $\Delta P = 0$ alternately appeared. The deteriorated gas flow field gradually formed during $\Delta P = 100$ was recovered by making $\Delta P = 0$. At 530 seconds the amount of PM2.5 particulate pollutants captured reached 4301, remaining 57.0%. Simulation results show that the active control method of periodic rectangular wave can greatly increase the captured amount of PM2.5 particulate pollutants.
Figure 7. Relationship between active control method of fan gas flow field and residual quantity of PM2.5 particulate pollutants in the room.

Figure 8 shows the streamline diagram of air flow at different times and the timing diagram of fan control in the 4th case. As shown in Figure 8 (a), the gas flow field tends to deteriorate at 310 seconds, so at the moment, \( \Delta P = 100 \) was changed to \( \Delta P = 0 \). The gas flow field was constantly changing at each time point in Figs. 8 (b)-8 (f), and almost return to symmetrical flow field in Figure 8(f). As shown in Figure 8 (f), \( \Delta P = 0 \) was converted to \( \Delta P = 100 \) at 360 seconds, and the velocity of capturing particles was accelerated (Figure 7). From Figure 8(g) to Figure 8(m), the gas flow field is gradually deteriorated, and the flow field at 430 seconds (Figure 8(m)) is similar to that at 310 seconds (Figure 8(a)). It can be calculated from the values of \( \Delta P \) at different times shown in Figure 8 that the cycle of the periodic rectangular wave is 120s and the duty ratio is \( 70/120 = 58.3\% \).

The iterative residual curve (Figure 9) of the active control method of gas flow field based on periodic rectangular wave shows the same periodicity as the periodic rectangular wave, and the residual has a trend of increase at the stage of \( \Delta P = 100 \), and decreases gradually at \( \Delta P = 0 \).

Figure 8. Airflow streamline diagram of periodic rectangular wave control method.
4. Actual test
On a haze day, the windows of the simulation room were opened to allow outdoor PM2.5 particles to diffuse into the room and were closed when PM2.5 value displayed on PM2.5 detector no longer changed in every position of the room. As can be seen in Table 2, active control of flow field by electric fan can improve the PM2.5 purification velocity and effectiveness of the air purifier.

Table 2. PM2.5 concentration changes with time.

| Time (minute) | 0  | 3   | 6   | 9   | 12  | 15  | 18  | 21  | 24  | 27  | 30  |
|---------------|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| air purifier  | 171| 110 | 79  | 55  | 52  | 42  | 34  | 30  | 30  | 18  | 15  |
| air purifier  | 173| 95  | 65  | 42  | 30  | 18  | 14  | 12  | 10  | 8   | 8   |
| and electric  |    |     |     |     |     |     |     |     |     |     |     |
| fan working   |    |     |     |     |     |     |     |     |     |     |     |

5. Conclusion and discussion
In order to give full play to the performance of air purifier capturing indoor PM2.5 and other particles, the effect of active control of indoor gas flow field by electric fan on the efficiency of the air purifier was studied. The physical model of the room including an air purifier and an electric fan was established by using GAMBIT software, and the gas flow field distribution and the capture of PM2.5 particles in a sealed room was simulated using Fluent software, whose results show that fresh air will not short-circuit and can be transported to more places in the room when the wind velocity of the air purifier is large. Electric fan can change the distribution characteristics of indoor gas flow field, and reasonable placement and wind velocity are helpful for fresh air to reach farther places in the room and unpurified air to inter the air purifier, however, high speed (high pressure difference ΔP) or long-time use of the fan will make the flow field more and more asymmetric or form eddy current, which is not conducive for the air purifier to capture PM2.5 particles, The active control method of the gas flow field based on periodic rectangular wave is proposed to maintain appropriate indoor gas flow field distribution relative to the air purifier in the room, which effectively improves the capture efficiency of PM2.5 particles, providing an economical, practical and effective method of improving indoor air quality.

The method of tracing and capturing PM2.5 particles can also be applied to the simulation and analysis of PM10 and particulate pollutants of other size. Alternating rectangular wave between ΔP=100 and ΔP=0 is used in the simulation room, namely the High Level of the rectangular wave is ΔP=100 and the Low Level is ΔP=0, the period of the periodic rectangular wave is 120 seconds and the duty ratio is 58.3%. For other rooms of different structure and size, different number of people and appliances, different number and location of air purifiers, active control of gas flow field can be
achieved by changing the high level and the low level, cycle and duty ratio, selecting triangular wave, sawtooth wave, step wave, etc. What’s more, the real-time detection technology of gas flow field distribution and particle distribution can be applied to realize the optimal control of the gas flow field by forming a closed-loop feedback control system.

References
[1] Zhang, Q., He, K., Huo, H. (2012) Cleaning China's air. Nature, 484:161-162.
[2] Huang, W., Cheng, X. J. (2017) Multiple regression method for estimating concentration of PM2.5 using remote sensing and meteorological data. Journal of Environmental Protection and Ecology, 18:417-424.
[3] He, K., Huo, H., Zhang, Q. (2002) Urban air pollution in China: current status, characteristics, and progress. Annu. Rev. Ener. Env, 27 :397-431.
[4] Chen, R., Zhao, Z., Kan, H. (2013) Heavy smog and hospital visits in Beijing, China. Am. J. Respir. Crit. Care Med., 188 : 1170-1171.
[5] Yin L. (2013) Evaluation of Air Purifier for Reducing Aerosol Exposure in the Office Room. Gdchem, 40:141-142.
[6] Corner, J., Pendlebury, E. (1951) The coagulation and deposition of a stirred aerosol. In: Proceedings of the Physical Society Part B, 64 :645.
[7] Shimada, M., Okuyama, K., Kousaka, Y. (1989) Influence of particle inertia on aerosol deposition in a stirred turbulent flow field. Journal of Aerosol Science, 20:419-429.
[8] Nazaroff, W. W., Cass, G. R. (1989) Mathematical modeling of indoor aerosol dynamics. Environmental Science and Technology, 23:157-166.
[9] Lu, W., Howarth, A. T., Adams, N. M., Riffat, S. B. (2010) CFD modeling and measurement of aerosol particle distributions in ventilated multizone rooms. In: ASHRAE Annual Meeting, 105:116-127.
[10] Zhang, Z., Chen, Q. (2007) Comparison of the Eulerian and Lagrangian methods for predicting particle transport in enclosed spaces. Atmospheric Environment, 41:5236-5248.
[11] Murakami, S., Kato, S, Nagano, S., Tanaka, Y. (1992) Diffusion characteristics of airborne particles with gravitational setting in an convection-dominant indoor flow field. In: ASHRAE Winter Meeting, 98: 82-97.
[12] Zhou, L. (2015) Numerical Simulation of Air and Particles Matter Distribution in Air-conditioning Room. Northeast Dianli University.
[13] Nielsen, P. V. (1996) Flow in air conditioned rooms. PhD thesis, Copnhagen. Technical University of Denmark, Copnhagen, Denmark.
[14] Gosman, A. D., Nielsen, P. V., Restivo, A., Whitelaw, J. H. (1989) The flow properties in rooms with small ventilation openings. Trans ASME Journal of Fluid Engineering, 2:115-127.
[15] Reinartz, A., Renz, U. (1984) Calculations of the temperature and flow field in a room ventilated by a radial air distributor. Int.J.Refrigrration, 7:308-312.
[16] Emmerich, S. J., McGrattan, K. B. (1998) Application of a large eddy simulation model to study room airflow. ASHRAE Transaction, 104: 1128-1140.
[17] Lee, H., Awbi, H. (2004) Effect of internal partitioning on indoor air quality of rooms with mixing ventilation—basic study. Building and Environment, 39:127-141.
[18] Li, L., Xu, W. (2003) Simulation and Analysis of Influence of Outdoor Air Volume upon Indoor VOCs Concentration Distribution. Contamination Control & Air-conditioning, 3:16-20.
[19] Zhang, T. (2008) Comparison of Floor Air Supply System under Cooling and Heating Modes. Building Energy & Environment, 27: 1-4.
[20] Meng, S. (2010) Dynamic Characteristic Analysis and 3D Numerical Simulation of a Marine Air Purifier. Master thesis, Shanghai Jiao Tong University, Shanghai, China.