The Design and Production of Ventilation Windows Based on Ionic Wind and Electrostatic Precipitation

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Abstract: In order to introduce clean and fresh air for indoor in the haze weather, we made an air cleaning window based on Ionic Wind and Electrostatic Precipitation method. It uses multi-line net-Ionic Wind as the power of ventilation, increasing air velocity and introducing air into the room; uses dual-zone wire-plate type of Electrostatic Precipitator, removing of particles, killing bacteria and viruses. We use the TSI Aerosol Monitor and Thermal Anemometer to measure the performance of the equipment. Experimental results show that the self-developed air cleaning window is suitable for the haze weather with a wide range of dust, and the efficiency can reach more than 92%; Wind speed can reach 1.24 m/s in vent steady uniform flow, and ventilation 203m^3/h, to meet the needs of indoor ventilation. Compared to the prior art, this equipment can greatly improve air quality indoors under the haze weather.

Key Words：ionic wind; electrostatic precipitation; room ventilation; indoor air quality; hazy weather

Haze attacked China in recent years, which has caused big damage to people's health[1, 2]。People always spend more time indoors than outdoors, we should pay more attention to indoor air quality. Air purifiers are the normal choice when people face the bad air. But the air purifiers in the market cannot work with the window open, which lead us to live in a closed environment. With the time goes on, the air in a closed room could be clean but not fresh. People wouldn't feel very well, either.

In order to prevent the particles from entering into our room and provide fresh new air for our room, we should remove them in the ventilation process, and our solution is to create a new purifier which can be installed with the windows through the wall, just like a "mask" of a house. This new device could reach two goals: remove the particles at one time, induce a continuous gas flow in the ventilation process.

There are two ways of the particle removing: mechanical filter and ESP(electrostatic precipitation)[3, 4]. The mechanical filter has a big wind resistance to the gas which would cause a big cost of energy if we use it in the ventilation process. And we must exchange the filter quite often because its life is only about one year or two. It is said that the effective filter is a bit expensive. The ESP has a good efficiency to the small particles and small pressure lost to the gas flow[5]. So this way is better to choose. But common ESP are usually too big to be installed with the window. We must improve the structure and change the dimension of the device until it is suitable for a window.

The average wind velocity outside is often below 2.3m/s, due to that there isn't enough ventilation power for a normal room to get enough fresh air. So we should provide extra power to complete the ventilation process. There are also two ways to provide the gas power: fan and ionic wind generator[6, 7]. Now most air purifiers consist of a mechanical fan. But the fan cost a big energy consumption and a big noise. Also the fan is too big, in a word, it is not very environmentally friendly to be installed in the room. The ionic wind is a new technology to generate the wind, an ionic wind is a gaseous fluid flow generated when charged particles (ions) are accelerated through a medium of neutral particles. The ions collide and exchange momentum with the neutral particles resulting in net motion. The ionic wind can help remove the dust and it cost a low energy consumption[8, 9]. The structure of a ionic generator is quite thin, the last but not the least, the ionic wind generator can work in silence to provide a gas flow of about 1m/s.

Based on the analysis above, we raised up the whole scheme：Based on the ESP and the ionic wind, we design a new purifier which can be installed with the window by improving the structure of the ESP and choosing the appropriate parameters of the ionic generator. This device could remove the small particles during the ventilation process and provide enough fresh and clean air for our room.

I Principle of the novel air purification

1 The scheme of air purification window

The scheme of this device is shown in the Figure 1. This device consists of the gauze, the electrostatic precipitator, the ionic wind generator and the ozone filter. The gauze could remove the big particles, the small particles could be collected by the electrostatic precipitator, the air flow is driven by the ionic wind produced by the ionic generator on the back, and the ozone filter could catalyze the decomposition of the ozone.

When the air outside is bad, we turn on the switch, the device starts working. The dirty air is driven by the ionic wind, going through the removal part without big particles with the help of the gauze. In the high voltage electrical field of the removal part, the small particles could be charged during the corona discharge, the bacteria would also be killed in the corona process. What's more, the CH_3OH could also be changed to CO_2 and H_2O.The small particles soon would be collected by the iron plate. Unfortunately, some extra ozone would be generated also, at the last part, the ozone filter based on the γ-Al_2O_3 could catalyze the decomposition of the ozone. Finally, the fresh and clean air could be sent to our room.

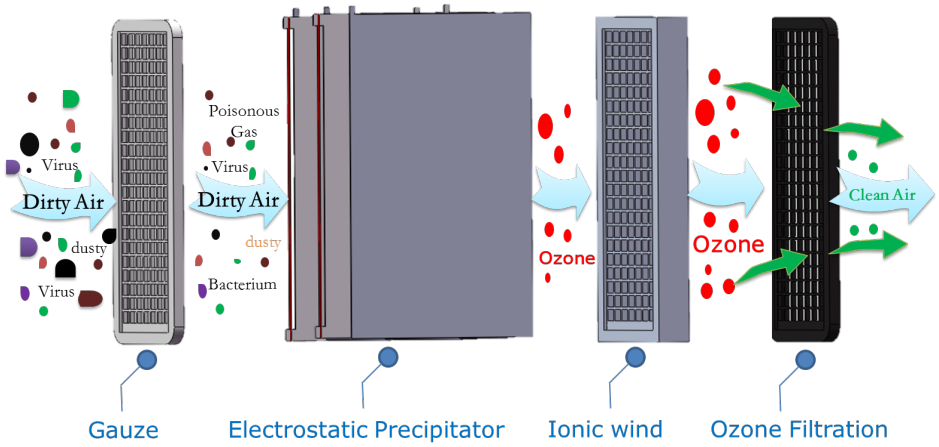


Figure 1　The schematic diagram of the decomposition of the device

2 Analyze of the key technology

2.1 Providing ventilation power with the help of the ionic wind

An ionic wind is a gaseous fluid flow generated when charged particles (ions) are accelerated through a medium of neutral particles. The ions collide and exchange momentum with the neutral particles resulting in net motion. The structure of the ionic wind generator including wire-to-net and needle-to-net. The wire-to-net structure could provide more area wind in the same volume. So we choose this structure to be a part of our device.

2.2 Remove the small particles with the help of ESP

There is a positive corona discharge near a corona wire in the electrostatic precipitator. The small particles could be easily charged in this area. The particles would be collected by the mental plates (the

negative electrode) driven by the electrical force in the high voltage electrical field. The structure of the ESP could be classified into two types: transverse plate and vertical plate structure. The vertical plate structure has little wind resistance to the gas flow which is good for ventilation. It is suitable for indoors air purification.

There are a lot of ways of increasing the efficiency of the ESP: Lower the wind velocity, Enlarge the length of the collection plate, Raise the approaching velocity. The ventilation couldn't be very well if we lower the wind velocity, the volume of the device would be bigger if we choose the second way, so we choose the last way to improving the efficiency of the ESP. We finally choose the double-district-structure as our structure of the ESP, it consists of two district: Charging district and collecting district. The collecting district was made of some mental plates which is parallel to the gas flow. This structure could provide a higher electrical intensity compared with other structure, thus the approaching velocity then turned high, so does the efficiency of the removal.

In a word, our device is made by improving the wire to plate structure. It is shown as Figure 2.

Figure 2 Double district electrical structure

(a) Before charging it

(b) After charging it

Figure 3 Straightening corona wires

2.3 ESP self-ventilating technology

We produced the air with the power source from the ESP, we complete two jobs: ventilation and purification with just one device. We finish the cost saving by this way. There are a lot of other advantages of this combination: the ESP has little wind resistance to the air flow which is good for ventilation, the ionic wind can help charge and remove the small particles. The two technology formed a good combination to raise the efficiency and the ventilation volume.

2.4 The way to make corona wire straight

The diameter of the mental wire we used is just 0.3mm. It can be buckled easily. It is as shown in Figure 3. It is hard to make it straight with the mechanical way. With the help of some books, we learned that we could let the wire be charged with the electricity in about 12V DC. The wire would turn hot to be easy to be straight. When the wire turned not that hot, it will keep being straight (shown in Figure 3).

The position accuracy of the corona wire has a big influence to the device. We use PCB plate to fix the corona wire by welding.

II Theoretical design of the device

Our device is a purification window, and the major part of our product is the ESP part and the Ionic wind part. The thickness of our device is an important parameter. We should have a good design to make sure that the voltage of the ESP part and the Ionic Wind part is equal, at the same time we should make sure the efficiency is reliable and lower the thickness of our device.

1 Parameter design

1.1 Air flow rate

The air flow rate is an important parameter of the indoor air purification device. According to the national indoor air quality standard GB/T18883-2002(China). The flow rate would be above 30 m^3/(h·person). We make a consumption: a room 3 persons, the device works 15h a day. So the total result could be calculated equals 2160m^3. The flow rate is 144 m^3/h.

1.2 The removal efficiency

The efficiency of the ESP has a positive relation with the energy we put in[10]. So the efficiency depends on what we need. According to the research, the PM2.5 is the major pollution in the haze weather, according to the environment air quality standard (China) GB3095-2012, the average mass concentration of the PM2.5 in a day is below 35μg/m^3, In 2013, the average mass concentration in a day of the PM2.5 in the highly polluted city Beijing is 646μg/m^3, so we should make sure that the removal rate of the device is above 94.58%, we choose the number of 95%.

1.3 The wind velocity

According to the text above, we know that the air flow rate is 144 m^3/h, according to the formula Q=V×S, the velocity of the air flow V is inversely proportional to the area of the inlet S. At first, we choose the velocity 1.5m/s because the velocity has influence to the efficiency, then the square meter of the inlet is 0.023m^2.

1.4 The thickness of the device.

The thickness of the device should be blew 240mm(the thickness of the outside wall in normal buildings), because it should be installed with the window in the wall.

2 Structure design of the removal part

The removal part is the most important part, in this region, the small particles would be charged and collected. The major design included corona way, corona voltage, purification efficiency and approaching velocity. The way of design is straight way analogy. First, we set up the relationship between models and the real one, then find the related working environment of the ESP. finally, we analyze the structure with the relevant theory.

2.1 Corona way and corona voltage

In order to lower the volume of ozone and NOx, improve the air quality, most air purifier designers choose the positive corona discharge.

The electrical intensity and the voltage of the discharge inception is two important parameters.。White has done a lot of research in this aspect，he raised up a semi-rational formula to calculate voltage：

（1）

In the formula：f ,the roughness of the corona wire 0.75；δ, relative density, 1；a, the radius of the corona wire，(m)；R distance between plates，(m).

The efficiency of the removal district and the approaching velocity

According to the experienced formula of the efficiency of the ESP, (Deutsch Anderson efficiency formula)：

Ошибка! Не указано имя закладки. （2）

In the formula：A the area of the collection plate，m^2**Ошибка! Не указано имя закладки.**；**Ошибка! Не указано имя закладки.**η ,the efficiency；**Ошибка! Не указано имя закладки.**Q the air flow rate，m^3/s**Ошибка! Не указано имя закладки.**； ,the approaching velocity，**Ошибка! Не указано имя закладки.**m/s。

According to the experience, we choose 0.2m/s as the approaching velocity.

2.2 The check of the parameters designed

According to the particle kinematics, the air flow velocity V could suits the formula following:

（3）

In the formula：L, the length of the collection plate，m； the approaching velocity，**Ошибка! Не указано имя закладки.**m/s； R, the distance between the plate, m。

According to the formula (1) (2) (3), the major parameters are as shown in the Table 1 following.

Table 1 The major parameter of the ESP part

Discharge inception voltage	The length of the plate	The width of the device	The height of the device	The removal efficiency	The distance between the plates	Total area of the collecting plate
7.6kV	60mm	99.5mm	200mm	99%	15mm	$0.72m^2$

3 The design of the ionic wind parameters

the function of the ionic wind generator is to produce the air flow. The ionic wind is a new technology. The principle of the ionic generation is a combination of fluid, electrostatic field, the diffusion of the electrons. Now, there is not any accurate formula of the wind velocity of the ionic wind. We decided to use semi-experienced way to choose the parameters of the ionic wind generator.

The major parameters of the ionic wind generator included the distance between the wire and the mental net.

The distance between the positive electrode and the negative electrode, according to the text above, the velocity is about 1.5m/s, we could infer the distance according to Zhuang Mengmeng's research. When the distance reaches 15mm and the voltage reaches 10.5kV, the wind velocity of the ionic wind could reach 1.5m/s

4 Conclusion

In summary, the device is composed of two main regions, dust removal district and air drive district. The dust removal district use double-zone electric field structure of the dust collector area is 18cm, the width is 16cm, the height is 30cm. Air driven area using multi - network structure, using an ion wind corona wire, wire spacing is 1cm. Therefore the overall thickness of the device length and the flow of dust area driven line distance and coupled with the screen and an active carbon screen width, total thickness is 24cm meet requirements in installation in the wall.

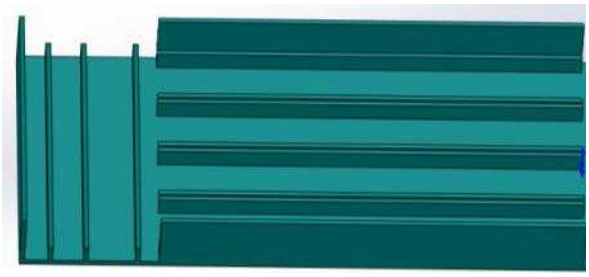
III Experiment results

The novel air purification window is composed of top cover, lower base, positive electrode plates, ground electrode plates and a ground electrode net for ionic wind. The top cover and base are made by engineering plastics, and featured high strength and good insulation and produced by 3D printing

technology. The plastic model is shown in Figure 4 (a), and the real object shown in Figure 4(b). The material of positive electrode plate sand ground electrode plates is 2A11 aluminum, and the material of corona wire is 65Mn steel. Both have good conductivity, easy processing characteristics. Using line cutting techniques to produce the electrode plate, and punch machine to fix corona wire at the positive electrode plate to produce corona.

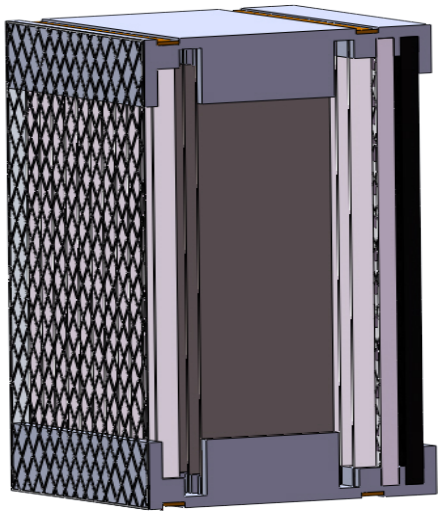
The parameters of lower base are as follows: the length is 110mm and wide 99.5mm. There are 7 slots, of which 4 are fixed in the ground plate, and 3 are fixed with the positive electrode plate. The slot width is 1.5mm, the slot depth is 10mm, the slot interval is 15mm, which is used for fixing the positive and ground electrode plates. On the base of the Z axis in the positive plate slot, the 1.5mm-width-groove is left to facilitate the electrode connection. And then separately on the top cover and lower base remain two wide 12mm, deep 3.3mm horizontal groove, for the fixed connection of the PCB. The plate part of the front and rear left transverse groove, used for fixing the window screen, ionic wind ne and carbon net. The window screen is glued to the lower base. The width of ionic wind level net and activated carbon net is separately 21mm and 10mm.

The air purification window assembly model is shown in Figure 4 (c), and the prototype is shown in Figure 4 (d). We have applied the national invention patent for the novel air purification window, and application has been accepted.



(a) the lower base 3D printing model

(b) the lower base real model



(c) the air purification window assemble

(d) the air purification window real model

Figure 4 The prototype of novel air purification window

1 Introduction to instruments

1. Using high voltage DC power supply to provide high voltage(Brand：Dong Wen，Type：

DW-P503-1ACDF，Voltage range：0-50kV)

2. Using fuming tablets to produce smog;

3. Using thermal anemometer to get the wind velocity(Brand：KANOMAX，Type：MODEL KA23/33，Speed range：0~5m/s);

4. Using aerosol detector to measure the value of $PM_{2.5}$ and PM_{10}(Brand：TSI，Type：DUSTTRAK^{TM}DRX-Model8533，Concentration range：0~150mg/m^3);

2 1m³ sealed box purification experiment

Igniting 1 fuming tablet in a 1m³ sealed and transparent box and after a few second the smog would full of the box and the air purifier cannot be seen by naked eyes. Then, turn on the air purifier and give the rated voltage and start air purifying. We record the process of the smog collecting by this air purifier, and we take a photo of it every 30 seconds. we use the TSI aerosol detector to record the curve of $PM_{2.5}$ variation in two minutes. The experiment system is shown in Figure 5, and the phenomena is shown in Figure 5 and the curve of PM2.5 variation is shown in figure ,

(a)device running 0s **(b) device running 30s** **(c) device running 60s** **(d) device running 90s**

Figure 5 Photos of the 1m³ sealed box purification experiment

From the Figure 6，we can conclude that after igniting the fuming tablets, the $PM_{2.5}$ concentration increases quickly. With the air purifier turn on, the value steadily decrease. After 2 minutes, the $PM_{2.5}$ concentration of the sealed box is lower than 1mg/m^3, which means the air purifier can filter small particles quickly and effectively.

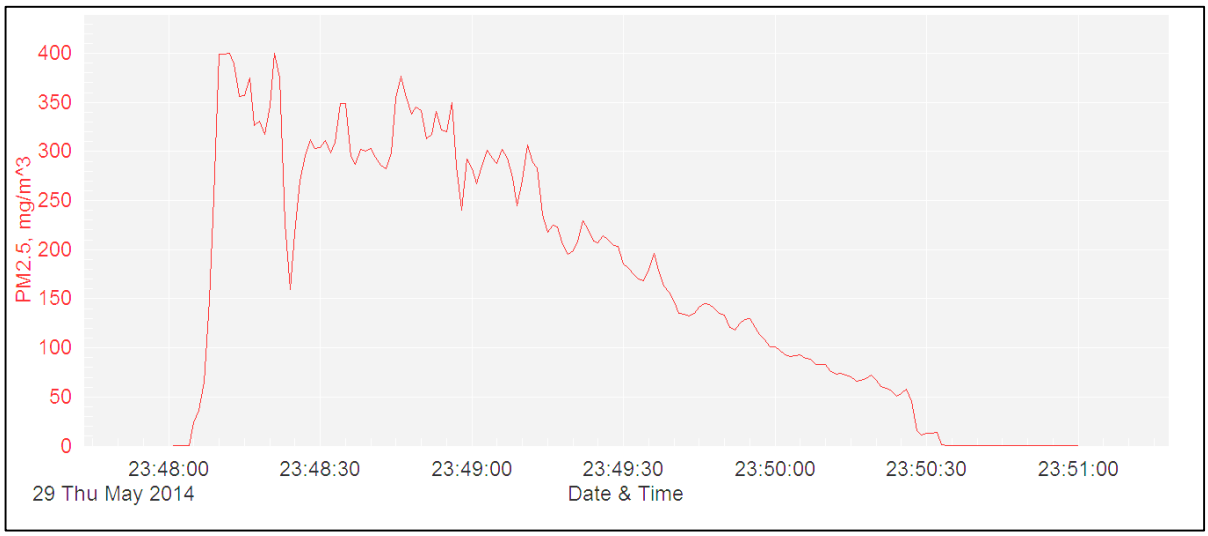


Figure 6 The origin data of the 1m³ sealed box purification experiment

3 Experiment on simulation of the haze weather

Firstly, we ignited only one cigarette in the $1m^3$ zone, and let stand for a minute. The air in the box was regarded as the still haze air, and the $PM_{2.5}$ concentration is up to $4000\mu g/m^3$. The space outside the box as the indoor environment in the haze weather. The TSI aerosol detector recorded the curve of $PM_{2.5}$ variation at the air outlet of the window in a minutes with the power on and off separately to make a comparison, the thermal anemometer could measure the wind velocity at the outlet of the device, the real experiment condition is shown in Figure 7.

Figure 7 Experiment on simulation of the haze weather

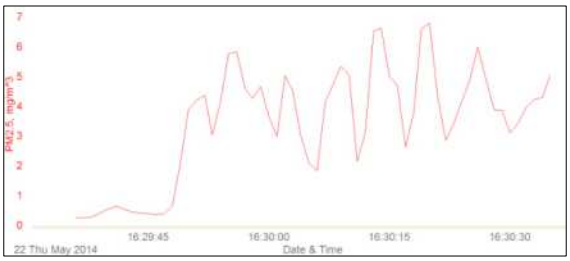
Figure 8 Experiment on 1m³ sealed box purification

During the 1 minute when the air purifier was turned on, we measured the wind velocity in outlet vent 6 times, and the results is shown in Table 2. This table proves that the velocity of ionic wind is 1.52m/s。

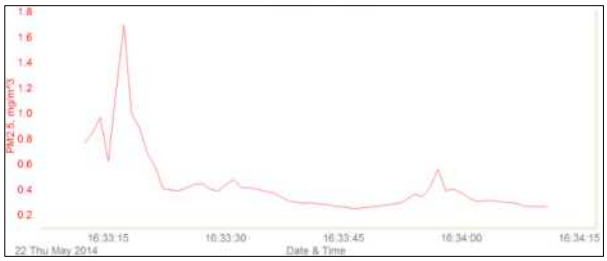
Table 2 the wind velocity in outlet vent

Serials	1	2	3	4	5	6	Average
Velocity (m/s)	1.48	1.62	1.68	1.41	1.39	1.52	1.52

The test continues in 2 minutes. The curve of variation of $PM_{2.5}$ concentration at the air outlet of the window is showed in Figure 9, the (a) and (b) separately show when the air purifiers is turned on and off. Through the Figure 9 (a), we can get the average value of the $PM_{2.5}$ concentration C_0 during 1 minute when the air purifier is turned off, which is $4420\mu g/m^3$, on the contrary, the average value when the air purifier is turned on is $328\mu g/m^3$. By dust removal efficiency calculation formula, we can get the efficiency can up to 92.8%



(a) When the device is turned off



(b) When the device is turned on

Figure 9 the origin data of experiment on simulation of the haze weather

IV Practical analysis

1 Innovations

（1）Combining windows with air purifiers and installing air purifiers on the wall just like wearing a mask for houses, which can forbid the pollutants from coming into the houses and collect the small particles when it comes into houses with air flow. This novel air purification windows have 96% dust removal efficiency and 203m3/h ventilation volume and meet the need of users for fresh and clean air.

（2）Using ionic wind as air flow driver in ventilation. This products uses multi-line net-ionic wind structure to produce steady and uniform air flow with the velocity reached 1.24 m/s, in order to accelerate the air flow and increase ventilation quantity. The evident advantages of ionic wind is super thin and ultra-silent, which facilitates shorten the width of products and the usage of it in calm environment.

（3）Realizing integration of ionic wind tech. and electrostatic precipitation tech. Setting the rated voltages of ionic wind and ESP in the same value through connecting the corona pole of ESP with the positive pole of ionic wind, and by this we can only use one voltage source to produce ionic wind and ESP, which saves one voltage source and reduce the cost and simplify the structure of circuit.

2 Market outlook

Product superiority: This product set the ventilation and dust removal as a whole and can effectively remove pollutants in airflow, initiative to achieve ventilation, send the fresh air into houses. The experiments showed that when the concentration of PM2.5 reached 5000μg/m^3 in the wind inlet, the air PM2.5 concentration is only 196μg/m^3 in the wind outlet. The dust particle size range is wide, the vent wind speed reached 1.24m/s, ventilation volume of 203 m^3/h; the product is placed in the wall, does not occupy the indoor space, low energy consumption, low cost, no secondary pollution.

Market demand analysis: Due to the frequent haze weather, air purifiers are sold well in market, but the existing air purifiers cannot achieve active ventilation. Therefore it cannot meet people's needs for indoor fresh air. So people need a kind of household appliances which can simultaneously achieve ventilation and dust removal.

Potential customer analysis: This product is suitable for home life, public places, and the laboratory which needs clean environment.

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