

An Investigation into Effect of Air Distribution on the Indoor Air Quality

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SUMMARY

The air distribution is a realizing form of indoor flow field, which plays a vital role to indoor air quality in the design of Heating , Ventilation and Air Conditioning. The average temperature and air speed in working area are closely related to air distribution, and the main factors that affect such two indices are the form, position, quantity of air outlet as well as the velocity, temperature of air supply. This article discusses the effect of air distribution on indoor air quality.

INTRODUCTION

As the healthy environmental protection idea goes deep into the public gradually, how to raise indoor air quality becomes a problem of people's concern. People are also show a tremendous expectation that the air conditioning can improve the indoor air quality. The relevant expert also puts forward the thinking—"to the direction of the healthy air conditioning development". How to improve air quality in the design for air conditioning has become an important study topic in the modern air conditioning technique. This article will make an initial study that the air distribution affects on the indoor air quality in the design air condition system.

INDOOR AIR QUALITY

Concept of the indoor air quality

The formation of the indoor air quality concept is a gradually perfecting process. The indoor air quality differs from an indoor pollution. At first definition of the indoor air quality meant a series of pollutant concentration index. However, along with research of going deep into continuously, people discovered that a single pollutant concentration index can't reflect the indoor air quality accurately. People don't feel comfortable in the room with low pollutant concentration. So in a narrow sense, the

indoor air quality can be regarded as the contaminative degree of smoke, dust, harmful air and microorganism. Speaking from the broad sense, the indoor air quality still include thermal environment parameter, such as temperature, humidity and flow speed etc. The indoor air quality is also closely related with the subjective feeling, mentality and the physiology conditioning of the occupants.

Main factors affecting to the indoor air quality

The factors affecting the indoor air quality mainly are the air conditioning system, indoor pollutant and deterioration of outdoor air. As figure 1:

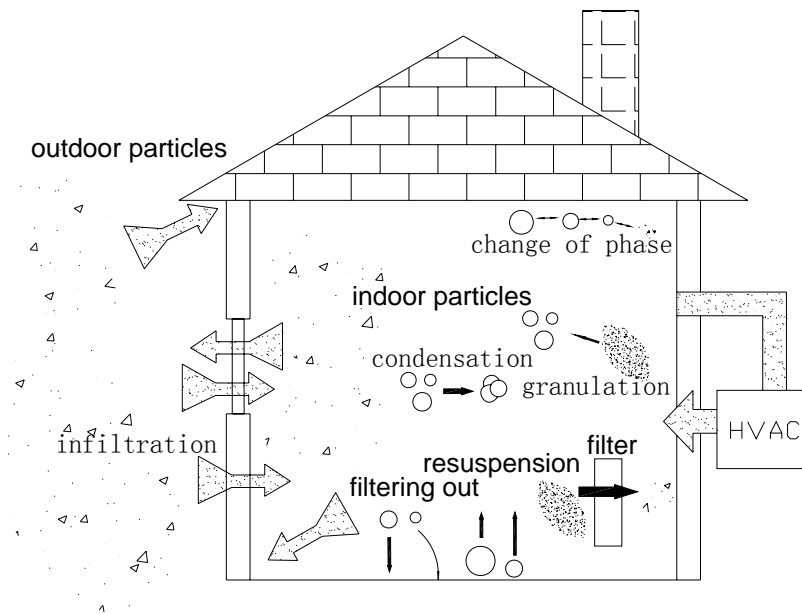


Figure 1

Generally speaking, the main factor affecting the indoor environment quality are: Temperature, relative humidity, air velocity, amount of fresh air, carbon monoxide, carbon dioxide, ozone, formaldehyde, benzene, respirable particles, the volatile organic compound, radon and etc.. Particularly in recent years a great amount of high business buildings has been built. The personnel's density increase continuously. A great amount of materials for decoration to be used, shortage of fresh air occupied, and unilateral pursuance for thermal comfort provided by air conditioning system, all of these worsen the indoor air quality.

Among them, the necessary parameter that insures thermal comfort in the environment is the temperature, relative humidity, the air velocity and etc. The sense of human body to the air environment not only lies on the chemical traces in the air, but also related with the temperature and humidity. So the suitable humidity can improve a people's requirement for air quality. The fresh air can dilute the indoor harmful air and make the air quality satisfied the request for work, living and health.

There are a great lot of kinds of pollutants influencing the indoor air quality, mainly have: inhalational particles, carbon monoxide, carbon dioxide, formaldehyde, volatile organic compound and etc..

The polluted outdoor air will impact the indoor air quality certainly. The outdoor air usually enters through fresh air system, doors, windows and fresh air system. At present in the air conditioning system, currently used air filter just trap the dust. It can't purge harmful gas and the germ. When outdoor air is polluted seriously, the volatile gas of organic compound and germ will send to air-conditioned rooms with the air conditioning. It makes indoor air quality grow worse.

THE VENTILATION AND AIRFLOW DISTRIBUTION

Ventilation processes

Ventilation process actually is an organized air renewal system. In order to altering the temperature, humidity and quality we replace the indoor air with fresh air. At present there are two modes of air distribution in the air-conditioned room. One is mixing ventilation based on dilution principle, another is displacement ventilation based on the thermal convection.

The typical scheme of mixing ventilation has ceiling and high-level side air supply. These two schemes of air distribution make the work area placed in recirculation zone. Handled fresh air is being sent in from the upper part of room with a certain speed. It merges with the hot contaminated air at first, and then is being sent into work area by backflow after mixing. Adopting this scheme of ventilation, the fresh air inhaled by indoor person has already been polluted during the period of ventilation. Setting out from the view point of air quality, the second scheme of air distribution would be better than the first one.

The devices of the displacement ventilation are often placed in the vicinity of floor. In this case the handled fresh air is being sent in directly to the work area at low speed (<0.5 m/s) and forming a thin layer as a air lake just above the floor because of its higher density. The supplied fresh air is spread out in the lower part of room, it does not mix with the upper hot air due to low turbulence intensity of flow. When the fresh air comes into contact with hot surface (such as human body and hot equipment) and is being heated, then rising upwards by natural convection. At the same time, the polluted hot air is driven by fresh air flow and is departing from the work area to the upper part of room and finally is extracted by exhaust ventilation system. The indoor air has stratification phenomenon owing to the density difference of the air at the different levels. The denser clean air (lower temperature) sinks in a lower part of room space and the lighter muddy air (higher temperature) rise to the upper part in the room. Thus the indoor persons situated in the work area can inhale fresh air immediately.

Air distribution

The air distribution is also called air current organization or air current distribution. It is a measure for reasonable air movement and organized flow of air in a ventilated room and for avoiding the formation of dead space and vortex. The mission of air distribution is to determine the location of air inlets and outlets according to the room geometry, technological process, personal position, character of pollutant and disperse conditions, and to make a reasonable air flow pattern. Thereby the temperature, humidity, velocity and cleanness of air within the work area could meet the technological and hygienic requirements.

According to the collocation of air inlets and outlets, there are the following schemes: side wall inlet and side wall outlet, ceiling diffuser, ejector system, ejector type grille, grille with direction blades, ceiling outlet, T-bar slot air diffuser, fan with backward curved blades, side wall register of horizontal and vertical louvers and shutters, floor extract grating, rectangular duct air supply and return opening with damper, round duct air supply and return openings with damper, mesh type air return opening, return grille and etc.

The effect of ventilation and air distribution on indoor air quality

We introduce the concept of efficiency of air exchange and efficiency of ventilation. The efficiency of air exchange is defined as the ratio of real resident time of air in a room to the theoretically shortest resident time of air. It shows the effectiveness of air exchange and is a criterion for assessment and is independent of air distribution. The schemes of ventilation and air distribution will influence the effectiveness of air exchange, dilution and removal of pollutant from indoor; therefore it could be a different sense of occupants to the air quality.

Increasing the fresh air amount supplied alone, it could not dilute the pollutant concentration properly, because the different air distribution scheme can cause different effectiveness of pollutant removal. Hence a concept of ventilation efficiency has been introduced. Ventilation efficiency is defined as a ratio of the pollutant concentration at air outlet to the average indoor concentration of pollutant. It means the grade of indoor pollutant removal and is an important index for assessing room ventilation. One employ a suitable air distribution scheme under the same conditions (pollutant and its emission rate, quantity of air supplied), if such a scheme can maintain a stable pollutant concentration or can reduce the initial pollutant concentration more quickly, it is to be said that this scheme has a higher ventilation efficiency and is more favourable for raising the indoor air quality.

When designing ventilation and air-conditioning system of a building, one should adopt various schemes of air distribution according to the size and use function of the building. If there are two schemes of air distribution for choosing, one is high-level supply and low-level return and another is vice versa. Generally speaking, the latter

scheme has advantage over the former in the respect of improving indoor air quality. In the case of low-level supply and high-level exhaust of air, the handled fresh air is sent to the lower part of room directly to the work area, and so called age of air has a minimum value. By virtue of the lower location of air inlet, lower speed of air discharged and higher density of fresh air supplied, the incoming air will spread out and occupy the whole lower part of room. As the age of fresh air is increasing, it comes into contact with hot source and then is being heated up. After that, hot air rise upwards due to natural convection, carrying pollutant and departing from the work area and finally discharging from the exhaust system.

The principles of design of air distribution system are as follows:

- To place the discharge grille as close as possible to the emission source of harmful matter or the region of higher concentration, and to remove the harmful matter quickly.
- To arrange the air supply diffusers as close as possible to the work area and avoid contamination of fresh air along the air low path.
- To make the air flow more uniform in the room space, reduce voetex and avoid excessive accumulation of harmful matter.

MATHEMATICAL ANALYZE OF EFFECT OF AIR DISTRIBUTION ON THE INDOOR AIR QUALITY UNDER DIFFERENT SCHEMES OF VENTILATION

3.1 The overall ventilation differential equation, its solution and application

According to the balance of pollutant matter, the increment of the indoor pollutant mass should be equal to the difference between the entering and exhausting amounts of pollution mass, namely

The increment of the indoor pollutant mass = entering pollutant mass + emitted pollutant mass — exhausting pollutant mass

Get a overall ventilation differential equation within d t time

$$\rho_{kr} V d\alpha_k = q dt \beta_k \rho_{ks} + k dt \rho_k - \Omega q dt \alpha_k \rho_{kr}$$

where: ρ_{kr} — density of the pollutant gas in exhaust air

ρ_{ks} — density of the pollutant gas in supply air

ρ_k — the density of the indoor pollutant emitted

α_k — concentration of the pollutant of exhaust air

β_k — concentration of the pollutant air of supply air

q — supply air rate

k —— emission of indoor pollutant source

V —— room volume

Ω —— ratio of densities of supply air to the exhaust air

Suppose the room volume is V , the initial concentration of formaldehyde in the room α_0 is 0.1341 mg/m^3 , indoor emission quantity of formaldehyde $k_{\text{甲}}$ is 0.12 mg/m^3 , and formaldehyde concentration of the supply air $\beta_{\text{甲}}$ is 0.1287 mg/m^3 . (For energy saving, the fresh air mixes with the return air)

Introducing $\varphi = \rho_{ks} / \rho_{kr}$; $\theta = \rho_k / \rho_{kr}$, and solving the overall ventilation differential equation, we could get the relationship between indoor pollutant and volume V at anytime:

$$\alpha_{\text{甲}} = \left[\frac{\varphi}{\Omega} \beta_{\text{甲}} + \frac{\theta}{\Omega} \frac{k_{\text{甲}}}{V} \frac{1}{q} \right] \left[1 - e^{-\Omega \nu \frac{q}{V} t} \right] + \alpha_0 e^{-\Omega \nu \frac{q}{V} t}$$

Suppose the experiment as a ideal case, the mixing coefficient (also called ventilation efficiency) $\nu = 1$, ventilation process is isothermal process, i.e. $\varphi = \Omega = \theta$.

1. Fixing the room volume, the relation of indoor formaldehyde concentration to the supply air rate and time:

Suppose the room volume $V=200 \text{ m}^3$, get the curves as shown in figure 2:

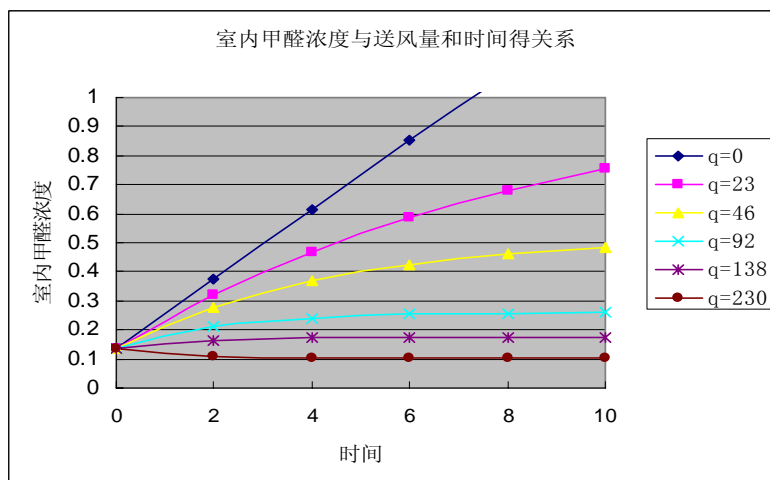


Figure 2

2. Fixing the supply air rate, the relation of indoor formaldehyde concentration to the

room volume and time:

Suppose the supply quantity $q=92 \text{ m}^3/\text{h}$, get a group of curves shown in figure 3:

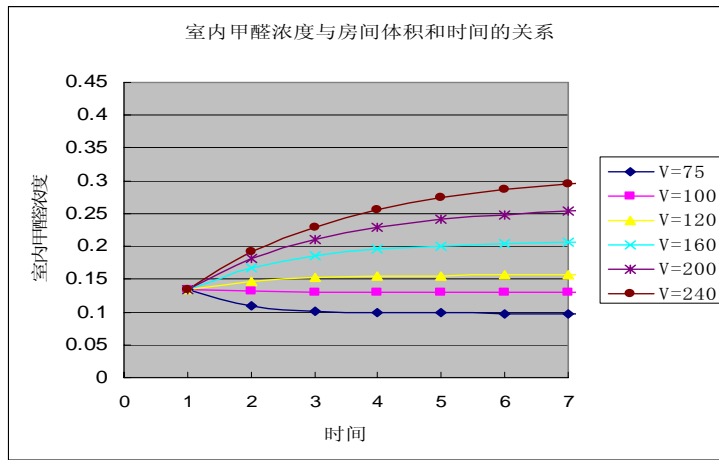


Figure 3

By analyzing above, for fixed supply air rate, the formaldehyde densities all attain a stable value after certain time. For the stuffy case ($q=0$), the formaldehyde concentration will rise straightly. The bigger the room is, the time is longer for attains a fixed value of formaldehyde. But the stabilized concentration value of formaldehyde is decided by the emitted quantity k of pollution source. It don't relate to the room volume.

CONCLUSIONS

From the analytical comparison above, we can conclude the following that: (1) the indoor air quality is not only decided by the size of the ventilation quantity, but also related closely to the air distribution. For the sake of getting better indoor air quality, we have to choice, dispose and control reasonably. (2) When designing a system we have to choose the suitable one according to the size and room shape, the amount of heat and humidity, position of pollutant source and concentration of pollutant in the room. (3) In engineering practice, the key problem is to keep the temperature, humidity, air velocity and pollutant concentration within a permissible region in the work area. So control of the air quality in the working area is not only the design pivot of the air distribution, but also the research direction of energy saving. (4) In the eyes of the control air quality, under supply is better when one building can use two types of air distribution: up supply and under supply.

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