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Analysis of Indoor Inhalable Particle Concentration under Variable Air Volume Air Conditioning System

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***Abstract*—In order to study the factors of influencing indoor particle concentration under the variable air volume air conditioning system, utilizing the law of mass conversion establish unsteady model on indoor particulate matter concentrations. As the inhalable particle for researchful object(particle diameter is less than or equal to ten micrometer), analyze the influence factors on indoor inhalable particle concentration theoretically on the basis of unsteady model, such as the indoor residual heat, indoor moisture load, outdoor inhalable particle concentration and initial concentration of indoor inhalable particle and obtaining the variable relationships about different factors and indoor inhalable particle concentration. Results indicate that, by controlling some relevant factors reasonably can reach for the purpose of reducing indoor particle concentration. Therefore, the unsteady model can provide some theoretical basis on lowering indoor particle concentration and improving indoor air quality.**

Keywords- Summer conditions; Variable air volume; Concentration of PM10; Unsteady model

I. INTRODUCTION

In the past twenty years, people pay more and more attention to the quality of indoor air because of the demand of people's quality of life[1-5]. GB 3095-2012*Ambient Air Quality Standards* [6]was promulgated in 2012, it requirements that the daily average of two level concentration limit of indoor PM10 was 0.15mg/m3. Meng Chong[7] has made a test about the concentration of PM10 in doors for the public buildings in Beijing and Changsha. The results show that the concentration range of PM10 in Beijing was 0.012~0.685 mg/m3, and the average concentration was 0.207mg/m3. This significantly exceeds the prescribed limit values of the two level. Thus, the particulate matter of indoor control is importance and urgency. This paper studied the impact of indoor residual heat, humidity, initial concentration and outdoor particulate matter concentration on the concentration of indoor particle effects in summer. And through the reasonable control of the various factors to achieve the purpose of reducing the concentration of indoor particulate matter

II. PHYSICAL MODEL SELECTION

The typical variable air volume system is selected as the research object, and the physical model of the system is figure1.

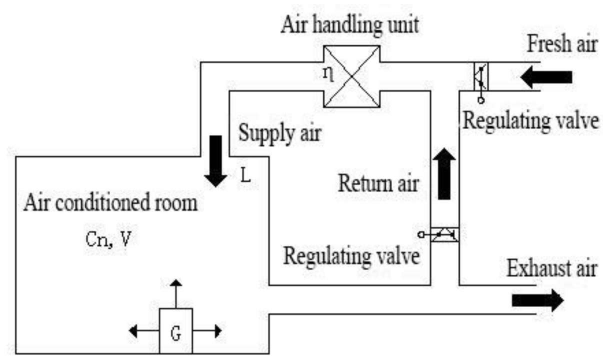

Figure 1. Variable air volume system

III. DERIVATION OF UNSTEADY STATE MODEL

In order to simplify the calculation, the following assumptions are made to the mathematical model established:

(1) Inhalable particles are uniformly distributed in the air conditioning room;

(2)The production rate of inhalable particles in the air conditioned room are stable;

(3) Ignore the possibility of inhalable particles and dust into the pipeline;

(4) Ignore the settlement of inhalable particles in the pipeline and indoor

According to the law of mass conservation available:

The quality of indoor inhalable particles increased= The quality of inhalable particles were sent into the room of the wind+ The quality of inhalable particles produced by indoor dust sources- The quality of the inhalable particles discharged by the exhaust air- The quality of the inhalable particles discharged by the return air

From the balance of air volume, the supply air is equal to the amount of exhaust and return air.

Therefore, it can be expressed as a formula:

$$V \cdot \frac{dC_n}{d\tau} = L \cdot (C_s - C_n) + G \quad (1)$$

Where Cn is the concentration of indoor inhalable particle, mg/m^3; Cs is concentration of inhalable particle in the supply air, mg/m^3; L is the amount of supply air, m3/h; G is the rate of indoor dust production, mg/h; V is volume of air conditioned room,m^3; dC_n is the increment of the concentration of inhalable particles in the room at $d\tau$ time interval, mg/m3; $d\tau$ is time interval, h.

G can be expressed as

$$G = G_p \cdot (\frac{F}{\beta} + P) \quad (2)$$

Where Gp is the amount of dust workers, mg/(P·h), Gp=10 is advisable; F is the area of indoor, m2; P is the total number of indoor personnel; β is the conversion coefficient of indoor area and personnel number, β =40 is advisable.

The formula (1) separation variable can get:

$$C_n = C_s + G \cdot L^{-1} + C \cdot e^{-L \cdot V^{-1} \cdot \tau} \quad (3)$$

When τ =0, Indoor inhalable particle concentration is the initial concentration, mg/m3.we can use C0 to express it.

$$C_0 = C_s + G \cdot L^{-1} + C \quad (4)$$

Thus

$$C = C_0 - C_s - G \cdot L^{-1} \quad (5)$$

So the equation of instantaneous concentration of the indoor inhalable particle in the air conditioning room is:

$$C_n = C_s + G \cdot L^{-1} + (C_0 - C_s - G \cdot L^{-1}) \cdot e^{-L \cdot V^{-1} \cdot \tau} \quad (6)$$

When $\tau \to \infty$, the stable value of the concentration of the inhalable particle in the room can be give:

$$C_n = C_s + G \cdot L^{-1} \quad (7)$$

By (7), the initial concentration of indoor inhalable particle is not related to the concentration of particulate matter after the running of the air conditioner.

A. When the Supply Air Volume is Expressed by Indoor Residual Heat

$$L = \frac{3.6 Q_x}{\rho c (t_n - t_s)} \quad (8)$$

Where Q_x is indoor sensible heat, W; ρ is air density, kg/m3, ρ =1.2 is advisable; c is specific heat of air, kJ/(kg·℃), c=1.01 is advisable; tn and ts are respectively the indoor and supply air temperature, ℃.

$$C_s = (1 - \eta) \cdot C_w \quad (9)$$

Where η is the total filtration efficiency of air handling unit; C_w is the outdoor air concentration of inhalable particle.

Combining equations (8), (9) and (6) gives:

$$C_n = (1-\eta) \cdot C_w + G \cdot \frac{\rho c (t_n - t_s)}{3.6 Q_x} + \left[C_0 - (1-\eta) \cdot C_w - G \cdot \frac{\rho c (t_n - t_s)}{3.6 Q_x} \right] \cdot \exp\left[- \frac{3.6 Q_x}{\rho c (t_n - t_s)} \cdot V^{-1} \cdot \tau \right] \quad (10)$$

B. When the Supply Air Volume is Expressed by the Indoor Moisture Load

$$L = \frac{Q_h}{\rho (d_N - d_S)} \quad (11)$$

Where Q_h is indoor moisture load, g/h; d_N, d_S respectively is the indoor and supply air moisture content.

Combining equations (9), (11) and (6) gives:

$$C_n = (1-\eta) \cdot C_w + G \cdot \frac{\rho (d_N - d_S)}{Q_h} + \left[C_0 - (1-\eta) \cdot C_w - G \cdot \frac{\rho (d_N - d_S)}{Q_h} \right] \cdot \exp\left[- \frac{Q_h}{\rho (d_N - d_S)} \cdot V^{-1} \cdot \tau \right] \quad (12)$$

IV. DISCUSSION AND ANALYSIS

The concentration of indoor inhalable particle is an important index to evaluate the quality of the air. In order to study the influence of indoor residual heat, moisture load, and outdoor particulate matter concentration, supply air moisture content in an unsteady state, the author takes an office as an example to do a numerical calculation. The calculation is as follows:

It is know that the office floor high is 3.6m, the area is 28.47m2 and the indoor volume is 102.5m3. Assuming that the per capita use of the area is 4m2. So there are 7 people in the office. Total filtration efficiency of air handling unit η is 80% and indoor temperature tn is 26^{0}C. Indoor moisture content dN is 12.5g/kg (a) and supply air temperature ts is 20^{0}C.

The above data into the formula (2) can get the rate of indoor dust production G is 77.12mg/h.

A. Influence of Indoor Residual Heat

Fig.2shows that the effect of air conditioning system on the concentration of indoor inhalable particle in the first two hours when the outdoor concentration of inhalable particle Cw is 0.15mg/h, and the indoor concentration of inhalable particle C0 is 0.4mg/m3. It can be seen from Fig. 2, when the air conditioning system is running, the concentration of the indoor inhalable particle decreased obviously. With the increase of indoor residual heat, the concentration of indoor inhalable particle can be reduced. When the indoor residual heat is 800W, the concentration of indoor inhalable particle can't be reduced to below the national standard even in two hours. It shows that when the indoor residual heat is lower, even the air conditioning system for a long time to run, indoor inhalable particle concentration is difficult to be reduced to the national standard. When the indoor residual heat reached 1300W, the concentration of indoor inhalable particle decreased to below 0.15mg/m3 in a relatively short time, and the increase of indoor residual heat can reduce the degradation efficiency of indoor inhalable particle.

B. Influence of Air Conditioning Room Humidity Load

Fig.3 shows that the influence of indoor moisture load on the concentration of inhalable particle when the outdoor inhalable particle concentration Cw is 0.15mg/m3, indoor initial inhalable particle concentration C0 is 0.4mg/m3 and supply air moisture content dS is 11.5g/kg(a). Other values are known. From Fig.3 as can be seen that when the indoor moisture load is less than 750g/h, indoor inhalable particle concentration is difficult to be degraded to 0.15mg/m3 within two hours. When the indoor moisture load is 900g/h, indoor inhalable particle concentration reached the national standard value within half an hour. It shows that the increase of indoor moisture load is beneficial to the decrease of the concentration of indoor inhalable particle, but with the increase of the moisture load, the influence of the moisture load on the indoor inhalable particle concentration is gradually reduced.

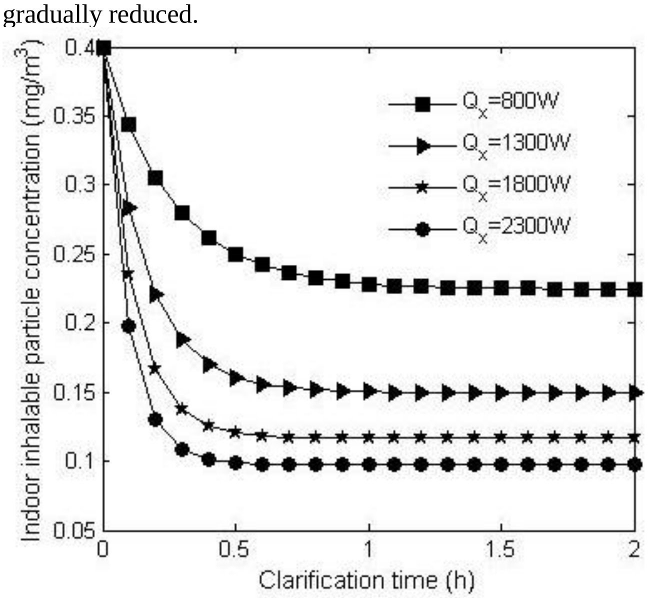

Figure 2. The relationship between indoor particulate matter and time under different indoor residual heat

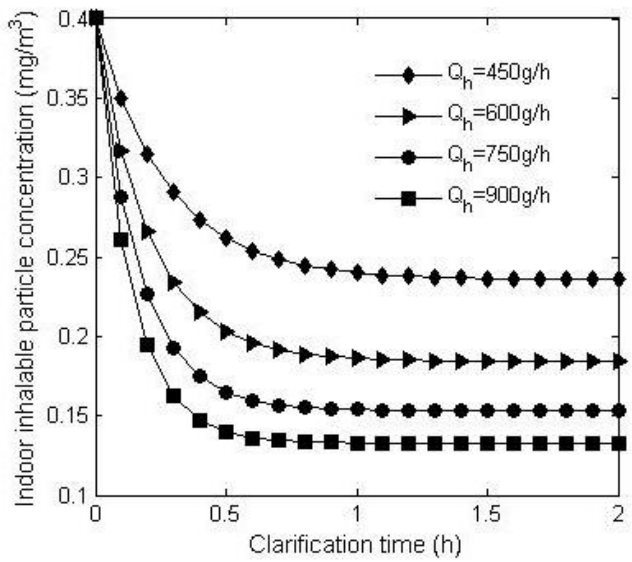

Figure 3. The relationship between concentration of indoor particulate matter and time under different moisture load

C. Effect of Outdoor Particulate Matter Concentration

Fig.4 shows the effect of outdoor inhalable particle concentration on indoor inhalable particle concentration when indoor residual heat Qx is 1500W and initial concentration of the indoor inhalable particle C0 is 0.4mg/m3. From Fig.4 as can be seen that when the outdoor inhalable particle concentration is 0.40mg/m3, indoor inhalable particle concentration decreased significantly within half an hour, and reached a stable state, but the indoor inhalable particle concentration can't reach the national standard value. When the outdoor inhalable particle concentration is less than 0.25mg/m3, the indoor inhalable particle concentration reached the national standard in the in a relatively short period of time. The result indicates that decreasing the outdoor inhalable particle concentration is conducive to improve indoor air quality. When the air conditioning system is stable, and the impact trend of the concentration of outdoor inhalable particle on the concentration of indoor inhalable particle is invariant. That is to say, they are liner relationship.

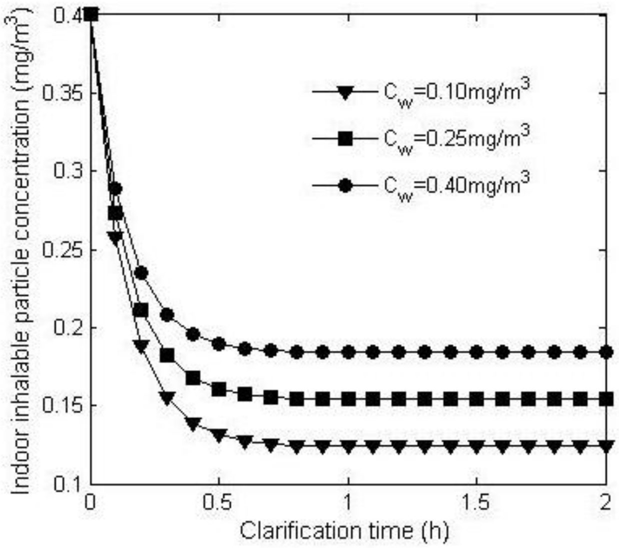

Figure 4. The relationship between the concentration of indoor particulate matter and time when the concentration of the outdoor particulate matter is changed

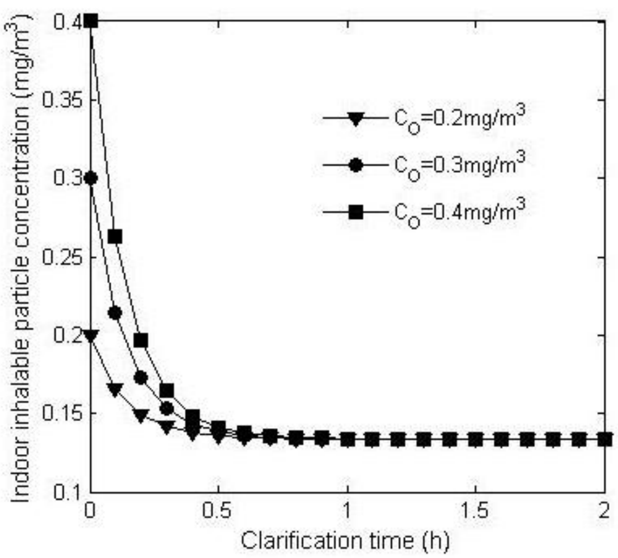

Figure 5. The relationship between the concentration of indoor particulate matter and time when the initial concentration of the particulate matter is changed

D. The Influence of The Initial Concentration of Indoor Particulate Matter

Fig.5 shows that the effect of initial concentration on the concentration of indoor inhalable particle when outdoor inhalable particle concentration Cw is 0.15mg/m^3 and indoor residual heat Qx is 1500W. From Fig.5 as can be seen that, the air conditioning system began to run, the higher the initial concentration of indoor inhalable particle, the greater the rate of decline in indoor inhalable particle concentration within half an hour. But no matter the initial concentration of indoor inhalable particle is 0.2mg/m^3, 0.3mg/m^3 or 0.4mg/m^3. After half an hour, the concentration of indoor inhalable particle can basically reach the stable value, and the stable value is the same. It shows that the concentration of indoor inhalable particle and the time to reach steady state are independent of the initial concentration after the air conditioner runs stably.

V. CONCLUSION

In the VAV air conditioning control system, through theoretical derivation and analysis of indoor inhalable particle concentrations can be seen, indoor residual heat and moisture load increase can reduce the concentration of indoor particulate matter, and with the increase of the concentration of both, the influence of indoor particles is reduced. The change of the initial concentration of indoor particulate matter does not affect the final steady-state value of the indoor particulate matter, which is only related to the purification efficiency of air conditioning start running to reach steady-state, and the higher the initial concentration, the greater the efficiency of the purification. The effect of outdoor particulate matter concentration and supply air moisture content on indoor air quality is relatively large. When the outdoor particulate matter concentration decreases, the indoor particle concentration decreases, and the outdoor particle concentration decreases linearly with the decrease of indoor particle concentration.

ACKNOWLEDGMENT

The preferred spelling of the word “acknowledgment” in America is without an “e” after the “g”. Avoid the stilted expression, “One of us (R.B.G.) thanks . . .” Instead, try “R.B.G. thanks”. Put applicable sponsor acknowledgments here; DO NOT place them on the first page of your paper or as a footnote.

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