Investigation of Feasibility of All-Fresh Air Supply in an All-air System

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Abstract: The feasibility of an all-fresh air supply in an all-air system is investigated in theory, and the problem of AHU-handling air in low efficiency in summer and winter conditions is analyzed. The air supply temperature is almost up to standards when a heat recovery unit is fixed in the air conditioning system.

Key words: all - air system; all fresh air supply; heat recovery unit

1. INTRODUCTION

The primary return air supply and secondary return air supply has been applied commonly in all-air system recently.

This mode of air supply can make full use of the indoor cool or heat, so as to be economical. However, air in different rooms will mix and the particles and bacterium spread in the whole building, when public health emergency occur. [1]

Concentrate of indoor particles and bacterium is more than outdoors, when there are dust sources or moving people indoors.[2] For this reason, Concentrate of indoor particles and bacterium indoor will decrease when all-air system works in all fresh air supply mode.

2. PROBLEM OF ALL FRESH AIR SUPPLY OF ALL-AIR SYSTEM

1) Whether can diameter of fresh air ducts satisfy all fresh air supply.

2) The load from outdoor air increase when air conditioning system works in all fresh air supply mode. Whether can the cool source and heat source satisfy the increasing energy consumption.

3) Enthalpy difference of handling air in all-air system is set in *Central-Station Air Handling Units*. [3] It needs to calculate that weather AHU designed with this standard can handling fresh air in a suitable supply state point.

4) Heat recovery unit can be fixed in air conditioning system, so as to decrease the load from outdoor air. In all fresh air supply mode, Heat recovery can make full use of excess heat and moisture excess in exhausted air, make the fresh air enthalpy approach the supply air enthalpy. Energy consumption can be saves and air supply effect can be improved.

3. PROBLEM OF FRESH AIR DUCT IN ALL-FRESH AIR SUPPLY

Fresh air duct should be designed in the condition of all fresh air supply, in order to satisfy all fresh air supply in transition seasons. But the diameter of fresh air ducts of many all-air systems can only fit for working in minimum fresh air requirement. For instance, in an all-air system, length of fresh air duct is 10 m, sides of duct are 320*320 mm, material of ducts is steel plates. There are two 90° elbow in fresh air tubes. The design air velocity is 2.5 m per second which is the recommended velocity value in air conditioning system for civil use. In this design condition, the noise received in room can be controlled under 25 dB, meanwhile pressure drop of the fresh air ducts is 3.2 Pa. When all-air system whose design percentage of fresh air is 15 percent runs in all fresh air supply mode, the fresh air flow rate will increase to 6.67 times, the air velocity in fresh air ducts will reach to 16.68 m per second, and pressure drop of fresh air duct is 152.8 Pa accordingly. At this moment, the fan can not satisfy air supply, furthermore noise caused by air flow will larger than maximum allowable indoor value.

4. CHANGING OF COOL OR HEAT SUPPLIED BY COOL OR HEAT SOURCE IN ALL FRESH AIR SUPPLY MODE

4.1 Summer Condition

Because comfort air conditioning system is discussed in this paper, so the design parameter obtained from *Code for Design of Heating Ventilation and Air Conditioning.* [4] In summer condition, indoor design temperature is in the range between 22℃ and 28℃, indoor design humidity is in the range between 40 percent and 65 percent. Outdoor design dry-bulb temperature is 33.2℃, wet-bulb temperature is 26.4 ℃ in BeiJing.

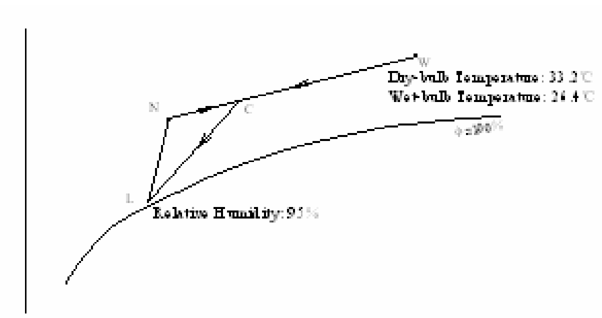

Fig.1 Process of air supply in primary return air supply mode

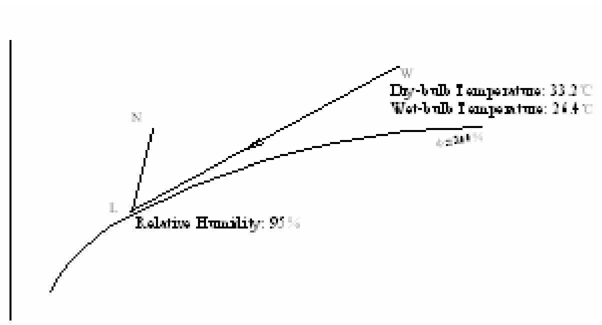

Fig.2 Process of air supply in all fresh air supply mode

Figure 1 shows the process of air supply in summer, which is in primary return air supply mode.

Figure 2 shows the process of air supply in summer, which is in all fresh air supply mode.

Specific cool of air handled by surface air cooler in AHU is equal to difference between mixing air specific enthalpy at state C and supply air specific enthalpy at state L when air conditioning system runs in primary return air supply mode, and specific cool of air handled by surface air cooler in AHU is equal to difference between outdoor air specific enthalpy at state W and supply air specific enthalpy at state L when air conditioning system runs in all fresh air supply mode, what is shown in Figure 1 and 2.

For instance, indoor design temperature is 25℃, indoor design humidity is 55 percent. Outdoor dry-bulb temperature is 33.2℃, wet-bulb temperature is 26.4℃, percentage of fresh air is 15 percent, air supply temperature is 15℃, air is supplied at apparatus dew point. According to calculation, specific cool supplied by cool source is 17kJ/kg in primary return air supply mode, and specific cool is 42kJ/kg in all fresh air supply mode, which is as 2.4 times as the former.

4.2 Winter Condition

In winter condition, indoor design temperature is in the range between 18℃ and 24℃, indoor design humidity is in the range between 30 percent and 60 percent. Outdoor design dry-bulb temperature is -12 ℃, Outdoor design humidity is 45 percent in BeiJing. The heating water temperature is 60℃.

The process of air supply in primary return air supply mode is that the fresh air in lower specific enthalpy mix with return air and is supplied in conditioned space through heat exchanger. When air conditioning system runs in all fresh air supply mode, fresh air is directly supplied in conditioned space through heat exchanger. For instance, indoor design temperature is 20℃, indoor design humidity is 35 percent. Outdoor dry-bulb temperature is -12℃, outdoor humidity is 45 percent, percentage of fresh air is 15 percent, air supply temperature is 35℃. According to calculation, specific heat supplied by heat source is 17kJ/kg in primary return air supply mode, and specific heat is 47kJ/kg in all fresh air supply mode, which is as 2.8 times as the former.

4.3 Saving of Energy Consumption since Heat Recovery Unit Is Fixed

According to calculation, in summer condition, specific cool supplied by cool source is 24kJ/kg since total heat recovery unit is fixed, which saves 42.86 percent of cool consumption, specific cool supplied by cool source is 36kJ/kg since sensible heat recovery unit is fixed, which saves 14.29 percent of cool consumption. In winter condition, specific heat supplied by heat source is 19kJ/kg since heat recovery unit is fixed, which saves 60 percent of heat consumption.

5. CHANGING OF AIR SUPPLY TEMPERATURE OF ALL FRESH AIR SUPPLY

5.1 Summer Conditioning

Figure 1 and Figure 2 show that the surface air cooler needs to have more heat and moisture transfer for specific air when air conditioning system runs in all fresh air supply mode.

Central-Station Air Handling Units stipulates minimum difference of specific air enthalpy between raw air and the air handled by surface air cooler is 16.75kJ/kg. Air supply temperature of all fresh air supply can be influenced in a certain extent, when surface air cooler is designed according to this standard. Air supply temperature of all fresh air supply was calculated as follow, through thermodynamics analysis of surface air cooler.

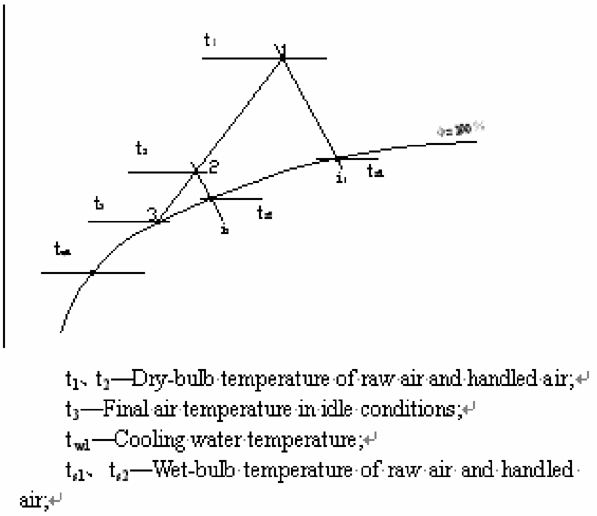

Fig.3 Change of air-water state in surface air cooler

Changing of air and water state in surface air cooler is shown in figure 3.

Two heat transfer efficiency was used to represent the capability of heat transfer of surface air cooler, when heat and moisture transfer in surface air cooler:

1) Total heat transfer efficiency of the surface air cooler, as described as follow

$$\varepsilon_1 = \frac{t_1 - t_2}{t_1 - t_{w1}}$$

Where

t_1, t_2 - Dry-bulb temperature of raw air and handled air;

t_{w1} - Cooling water temperature

2) Universal heat transfer efficiency of the surface air cooler, as described as follow

$$\varepsilon_2 = \frac{t_1 - t_2}{t_1 - t_3} = 1 - \frac{t_2 - t_{s2}}{t_1 - t_{s1}}$$

Where

t_3 - Final air temperature in idle conditions

t_{s1}, t_{s2} - Wet-bulb temperature of raw air and handled air

And $\varepsilon_1 = f(K_s, G, W)$, $\varepsilon_2 = f(v_y, N)$.[5]

It can be concluded that when the air supply mode of air conditioning system altered from primary return air supply to all fresh air supply, total heat transfer efficiency and universal heat transfer efficiency of the surface air cooler keep constant, if air supply flow rate, cooling water flow rate and model of surface air cooler don't change. That is the theory basis for calculating air supply temperature of all fresh air supply.

Reference [5] brings out a new method for thermodynamics analysis of surface air cooler - method named Equivalent Dry Cooling Condition. The heat transfer arose by the change of moisture transfer can be calculated by using this method in lower calculation error (about 1 percent) and higher precision. The equation of this method is showed as follow:

$$a t_3^2 + b t_3 + c = 0 \qquad (1)$$

$$a = 0.020473n + 1.90892 \times 10^{-4}$$

$$b = 0.103746n + 1.018241$$

$$c = 4.47862n - m$$

$$m = i_1\left(1 - \frac{\varepsilon_1'}{\varepsilon_2'}\right) + 1.01\frac{\varepsilon_1'}{\varepsilon_2'} t_{w1}$$

$$n = 2.5\left(1 - \frac{\varepsilon_1'}{\varepsilon_2'}\right) - 1.84 \times 10^{-3} \frac{\varepsilon_1'}{\varepsilon_2'} t_{w1}$$

$$t_2 = t_1 - \varepsilon_2\left(t_1 - t_3\right) \qquad (2)$$

Where

ε_1' - Total heat transfer efficiency of the surface air cooler in equivalent dry cooling condition;

ε_2' - Universal heat transfer efficiency of the surface air cooler in equivalent dry cooling condition

When calculating, air supply state point and mixing state point in primary return air supply mode can be determined according to the minimum difference of specific air enthalpy between raw air and the air handled by surface air cooler, which is 16.75kJ/k. ε'_1 and ε'_2 can be determined consequently. t_3 can be determined by solving equation 1, and t_2 can be determined by solving equation 2. The outdoor dry-bulb temperature is 33.2℃, outdoor wet-bulb temperature is 26.4℃, air supply humidity is 95 percent, cooling water temperature of surface air cooler is 7℃. Air supply temperature of all air fresh supply, which changed from the one of primary return air supply when air conditioning system changed air supply mode, was calculated in different working conditions of indoor design temperature and relative humidity. The results are shown in Table 1.

Tab.1 Air supply temperature of all fresh air supply in summer condition

No	Indoor Design Dry-Bulb Temperature /℃	Indoor Design Relative Humidity /%	Air Supply Temperature of Primary Return Air Supply /℃	Air Supply Temperature of All Fresh Air Supply /℃
1	25	60	17	20.60
2	25	55	16	20.00
3	25	50	14	18.57
4	26	60	18	21.12
5	26	55	16	19.99
6	26	50	15	19.32
7	27	60	19	21.57
8	27	55	17	20.57
9	27	50	16	19.97

It is shown that air supply temperature of all air fresh supply was about 3-5℃ higher than the one of primary return air supply. So the air supply can't remove all the indoor excess heat and moisture excess, can only take on part of space cooling load in all air fresh supply mode.

Fixing heat recovery unit and changing cooling water temperature are two ways to decrease air supply temperature of all air fresh supply.

Tab.2 Air supply temperature when fixing heat recovery unit

No	Air Supply Temperature of Primary Return Air Supply /℃	Air Supply Temperature of All Fresh Air Supply When Fixing Sensible Heat Recovery Unit /℃	Air Supply Temperature of All Fresh Air Supply When Fixing Total Heat Recovery Unit /℃
1	17	19.33	17.36
2	16	18.78	16.59
3	14	17.47	15.22
4	18	19.95	18.15
5	16	18.92	16.91
6	15	18.30	16.08
7	19	20.53	18.93
8	17	19.61	17.74
9	16	19.05	16.91

Table 2 shows air supply temperature of all air fresh supply when heat recovery unit had been fixed. Air supply temperature decreased a bit, which is shown in results. Especially being handled by total heat recovery unit, air supply temperature was almost as same as the one of primary return air supply.

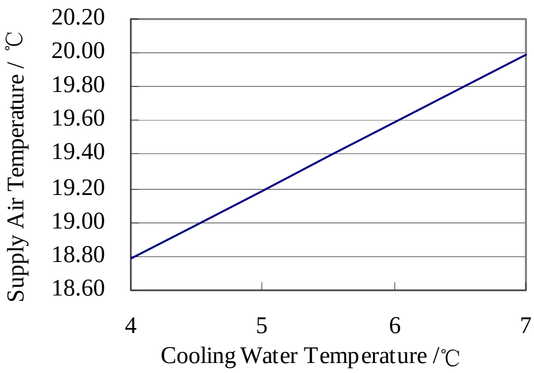

Fig.4 Air supply temperature change with cooling water temperature in all fresh air supply mode

In a working condition (Indoor temperature is 25 ℃, humidity is 55 percent, air supply temperature of primary return air supply is 16 ℃), air supply temperatures of all air fresh supply after changing cooling water temperature are shown in Figure 4. Decreasing cooling water temperature can improve air supply effect in a certain extent in all air fresh supply mode.

5.2 Winter Condition

In winter condition, the process of heating supply air only includes sensible heat transfer. Only universal heat transfer efficiency can be used in calculation of heat transfer accordingly. *Central-Station Air Handling Units* stipulates minimum difference of specific air enthalpy between raw air and the air handled by heat exchanger is 23.05kJ/kg. Based on this value, air supply temperature and mixing air temperature in primary return air supply mode can be determined. As a result of universal heat transfer efficiency keeping constant, air supply temperature of all air fresh supply can be calculated. The results are shown in Table 3.

Tab.3 Air supply temperature of all fresh air supply in winter condition

Air Supply Temperature of Primary Return Air Supply /℃	Air Supply Temperature of All Fresh Air Supply /℃	Air Supply Temperature When Heating Water Temperature Is 70℃ /℃	Air Supply Temperature When Fixing Heat Recovery Unit /℃
30	19.18	23.51	30.07
31	19.78	24.19	30.51
32	20.40	24.91	30.96
33	21.05	25.64	31.44
34	21.73	26.41	31.94
35	22.43	27.22	32.45
36	23.17	28.05	32.99
37	23.93	28.92	33.55

It is shown that air supply temperature of all air fresh supply was 10-13℃ lower than the one of primary return air supply. So the air supply can't take on indoor heating load. Fixing heat recovery unit and changing heating water temperature can elevate air supply temperature.

Air supply temperature had been markedly improved since heating water temperature increased to 70℃. The results are shown in Table 3.

After fixing heat recovery unit, all air fresh supply provided conditioned space an indoor environment with suitable temperature in maximum heat transfer efficiency of heat exchanger.

5. CONCLUSION

1) When all-air system works in all fresh air supply mode, noise caused by air flow may be larger than maximum allowable indoor value. Fixing silencer on fresh air ducts is a good way to solve this problem.

2) Cool consumption of all fresh air supply is provided fully only when refrigerating machine have enough excess in summer condition. Air supply temperature of all air fresh supply was 3-5℃ higher than the one of primary return air supply, so indoor temperature increase with about 3℃ accordingly. Person's normal work and rest is influenced in a certain extent in this condition. Decreasing cooling water temperature can make air supply temperature descend a bit. By fixing heat recovery unit, air supply temperature of all air fresh supply can descend, so as to satisfy the requirement of people's heat comfort and decrease cool consumption of cool source.

3) In winter condition, air supply temperature of all air fresh supply is too low to ensure the normal indoor temperature. Air supply temperature can increase when heating water temperature is elevated. After fixing heat recovery unit, air supply can take on indoor heating load.

4) Air conditioning system's working in all air fresh supply mode don't increase indoor heating load or cooling load in transition seasons. So if the noise arose by fresh air duct doesn't exceed the standard value, all-air system can work insusceptibly in all air fresh supply mode.

5) There are two points must be taken into account when choosing heat recovery unit:

I. In order to prevent intersectant contamination between fresh air and exhaust air, the heat recovery unit need to have good isolation.

II. Plate-fin and rotary heat recovery unit need large space when fixing, and heat pipe is more suitable to the air conditioning system that don't have enough space.

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