# VAV SYSTEM ANALYSIS

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## ABSTRACT

There are two kind of supply fan rotation speed control methods, one is the static pressure control method, the other is the float pressure control method. Simulation shows that they have different working point along the whole year. The supply air fan controlled with float pressure control method need low rotation speed and works on high efficiency, so the float pressure control method need only 30% fan operation energy of the static pressure control method. The layout of the air duct may influence the fan control method.

## INTRODUCTION

As the VAV system is getting popular in China, many problems are rising from the design, the operation as well as controls(Jiang 1997). According to investigation on several VAV systems in Beijing, the energy consumption changes in the range as large as between factors 1 to 1.5 due to different in design and control.

The supply fan rotation speed control method is one of the important factor that influence the VAV systems energy consumption. There two kind of control methods, One is the static pressure control method, which is set a static pressure at the fan export or at one point on the supply air duct. The other is the float pressure control method, using this mehthod, the supply air fan pressure head is just eaquel to the resistance of the supply air duct. The float pressure control method need the communication of the VAV box, so it is difficult to realize. Most of the VAV systems in the comercial buildings in Beijing are using static pressure control method. But some research work consider the float pressure control method should be used (Sun ,1997).

There are two kinds of supply air duct layout, one is the tree type, and the other is the looping type (Goswami 1986 and I.Khoo 1997). Different duct layout influences the operating effect of static and float pressure control method.

These former researches on the VAV systems control method and air duct layout are combined with the controller (for example PID), and they only give some qualitative result.

To guide the operation of VAV systems, this paper compare the different fan speed control stratergy with fan pressure head, rotation speed, efficiency and opration energy according to simulations. And also comparing the simulation result of looping and tree duct layout.

Table 1 Information of standard floor

| | |
|---|---|
| Conditioned area | 30200 $m^2$ |
| Lighting | 30 $w/m^2$ |
| Occupants | 10$m^2$/person |
| Equipment | 15 $w/m^2$ |
| Fresh air requirement | 25$m^3$/h/person |
| Set point | 22~26C, 40~70% RH |
| System type | VAV system |
| Air condition system running period | 8:00 am ~ 17:00 pm each day |

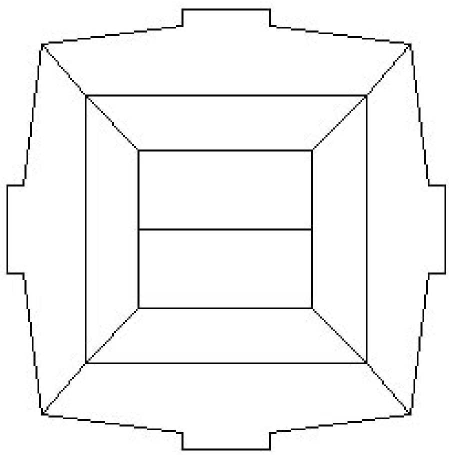


Figure 1: Drawing of standard floor

Figure 1 is the drawing of a commercial building in Tianjin of China. The middle is the machinery room, the around are office rooms. Each standard floor includes outer space and inner space. The depth of office room is about 15 meter. There are 30 floors in this building altogether. Table 1 shows the information of the building (standard floor). The external wall of the whole building is glass curtain wall.

## THE SUPPLY AIR AMOUNT AND THE SUPPLY AIR TEMPERATURE

Using simulation software DeST (Chen, 1999 and Jiang 1991), based on the whole year weather data, we can calculate the whole year cooling and heating load of the building. The VAV systems have a variable supply air amount, so the supply air temperature varied also. The optimal temperature is the most energy saving. Knowing the cooling load and the supply air temperature, then we can get the supply air amount of the whole year.

The whole year supply air volume of outer space shows in Figure 2, the max min and ave represent the maximum minimum and average supply air volume of the same day from 8:00 in the morning to 17:00 in the afternoon.

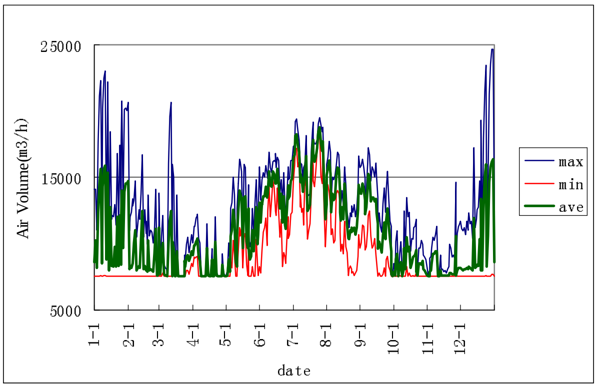
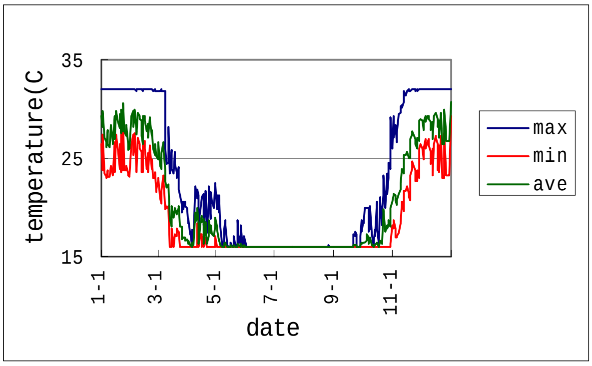



Figure 2: Supply air volume of the whole year

In winter and summer, some rooms in the building (for example north rooms in summer and south rooms in winter) have the large cooling or heating load of the all rooms, but the load of other rooms are little. In order to satisfy the room in each orientation, the supply air temperature can not be too high in winter and too low in summer. Figure 3 shows the whole year supply air temperature, the highest temperature is 32 C, and the lowest is 16 C.

In winter and in summer, the difference with the supply air and the room temperature can not be very large. Then the coldest room of the building will need very large amount supply air volume. In the spring and the autumn, the situation is different, the cooling load difference of all the rooms are very little, so the supply air volume is between the maximum and minimum. In spring and autumn, the outdoor temperatures are between winter and summer, so the supply air volume is smaller than winter and summer.

So in winter and summer the whole building's supply air volume gets the maximum values. In spring and autumn the supply air volume is between the winter and summer.




Picture 3: Supply air temperature of the whole year

Figure 4 shows the supply air volume of the south and the east orientation rooms. The largest supply air volume appears at different date.

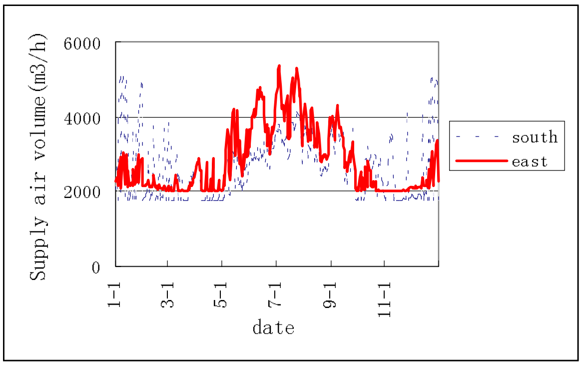



Figure 4: Supply air volume of the south and east rooms of the building

In the following paper, we will compares the differen fan speed control strategy and supply air duct layout of this building combined with the supply air volume simulation results.

## FAN CONTROL STRATEGY OF TREE DUCT

Picture 5 shows the one type supply air duct layout of the building refers in above paragraphs.

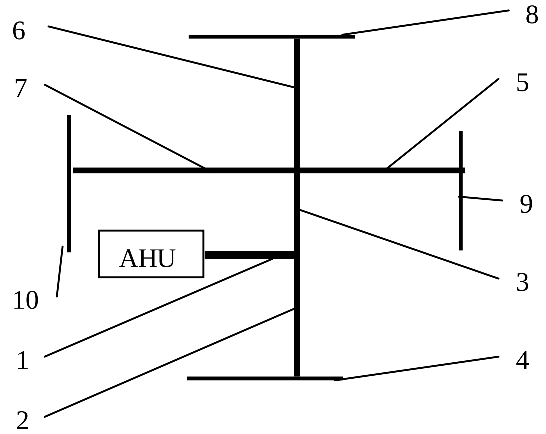



Figure 5: Tree type duct layout

Where AHU is the air-handling unit, 1,2,3…9,10 are supply air duct number.

With the known supply air volume, using simulation method, we can get the fan pressure head of the whole year.

Figure 6 shows the fan working point with three different control strategies.

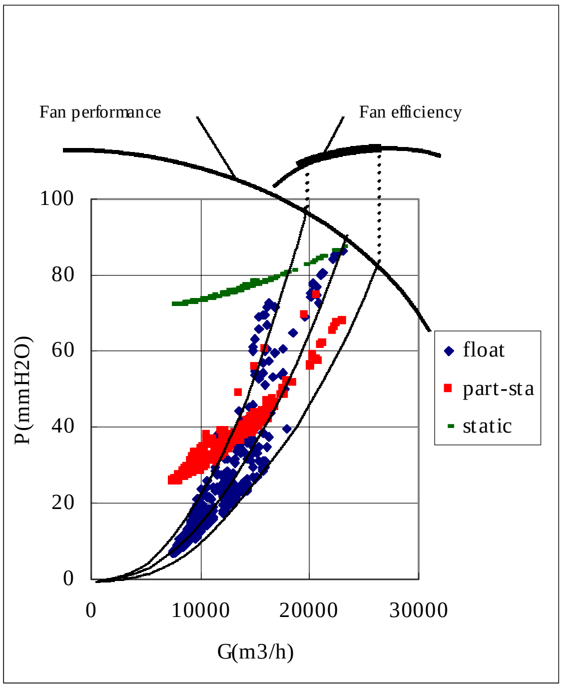



Figure 6: Fan working point with different control strategy of tree duct layout

Where float present the float pressure control method. Static presents the static pressure control method with static pressure point setting at the fan export. The part-sta present the static pressure control method with static pressure point at two part of the whole supply air duct (in Figure 5, it is at the export of duct 6).

Where G present the supply air volume, P present the fan pressure head.

According to simulation results, we can see running in the same air volume, three different kinds of fan speed control strategy need different pressure head. The float pressure control method's pressure head is the lowest, while the static pressure control method with the static pressure setting at the fan export needs the highest pressure head. The method with static pressure point setting at the two-part of the whole supply air duct needs fan pressure head between the other two kind methods.

Different fan working points have different running efficiency. Choosing one kind of centrifugal supply air fan, using simulation method can get the fan efficiency for each working point according to the relation between the air volume, pressure head and fan running efficiency.

The fan performance curve and fan efficiency curve also show in Figure 6. They come from the next formulas.

$$P = -2.016223\times10^{-12} \bullet \frac{n_0}{n} G^3 - 2.42035\times10^{-7} \bullet G^2 + 0.0028806 \bullet \frac{n}{n_0} G + 152.5 \bullet \left(\frac{n}{n_0}\right)^2 \qquad (1)$$

$$\eta = -5.79941\times10^{-14} \bullet \frac{n_0}{n} G^3 - 9.62606\times10^{-10} \bullet G^2 + 1.89455\times10^{-5} \bullet \frac{n}{n_0} G + 0.55 \bullet \left(\frac{n}{n_0}\right)^2 \qquad (2)$$

Where:

$P$ is the fan pressure head.

$G$ is the fan supply air volume.

$\eta$ is the fan efficiency.

$n_0$ is the design fan rotation speed .

$n$ is the variable fan rotation speed

In Figure 6, some fan working point locate in the high efficiency area, others not. The area include most of the point working with static pressure point setting at two-part of the whole air duct, some of the point working with float pressure control method, and only little part of the point working with static pressure point setting at fan export. Figure 7 shows the percentage of the fan working point locating in the high efficiency area for three different fan rotation speed control strategies.

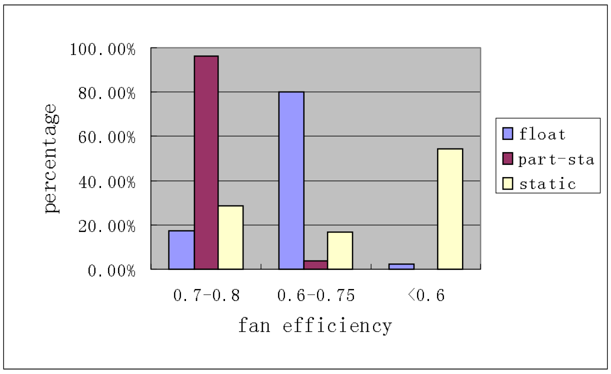



Figure 7: Fan efficiency distribution of different control stategy

With known fan working points and the fan performance curve, Using simulation method, we can also get the fan rotation speed. Figure 8 shows the whole year's fan rotation speed with different control strategies.

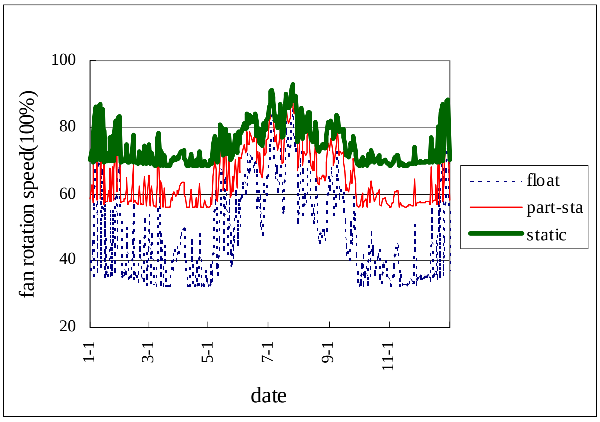



Figure 8: Fan rotation speed with different control stratergy

From Figure 8, we can see in winter and summer, the supply air fan controlled with three different methods all runs in high speed, it just because the supply air volumes are large in these two seasons. In spring and autumn, the situation is different.

Fan working with the static pressure setting at it's export has the highest rotation, next is the fan working with the static pressure setting at two-part of the whole air duct, the speed of the fan controlled with the float pressure runs in the lowest speed.

Knowing the fan supply air volume, pressure head, efficiency and rotation speed, then we can use simulation to get the fan running energy of the whole year.

How much difference between these three different control strategies? Figure 9 told us the answer. In Figure 9, the fan operation energy is only for the outer space one floor of the building refers in above paragraphs.

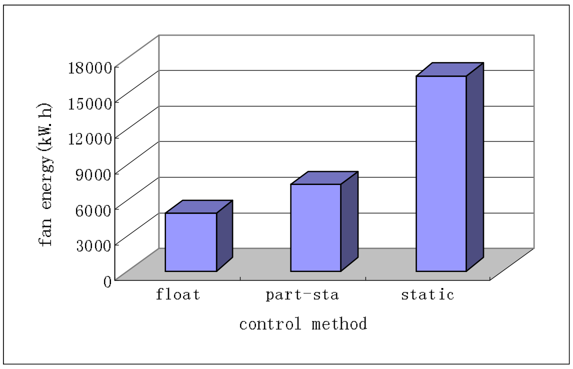



Figure 9 Fan energy with different control strategy

The float pressure control method consumes only 29.6% fan operation energy of the static pressure control method.

This building have 30 floors altogether, so the float pressure could save 350000(kW·h) fan energy comparing with the static pressure control method which sets static pressure point at fan export.

## FAN CONTROL STRATEGY OF LOOPING DUCT

Figure 10 shows the other type supply air duct layout of the building refers in above paragraphs.

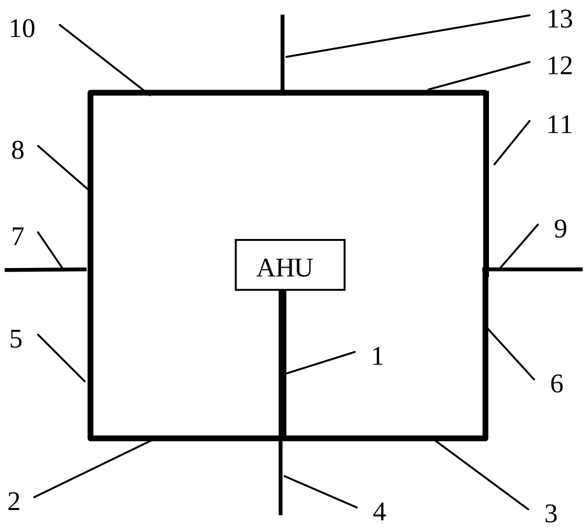



Figure 10: Looping type duct layout

The simulation results of the looping duct layout are similar with the tree duct layout.

Figure 11 shows the fan working point of three different control strategies for looping duct layout.

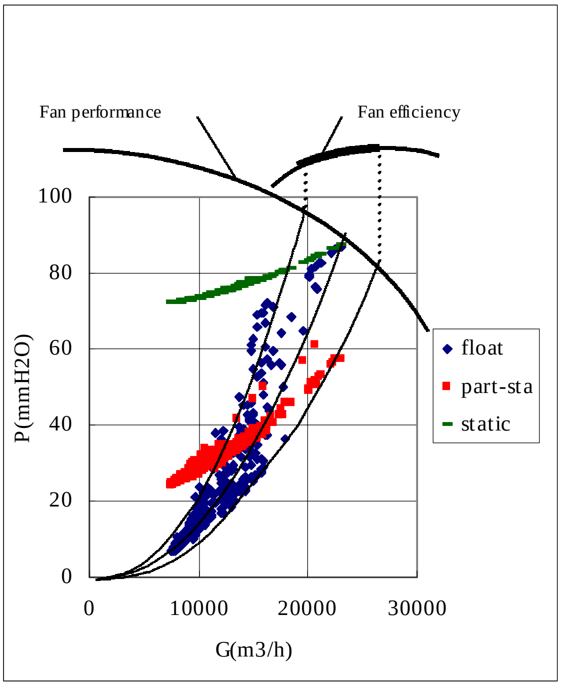



Figure 11: Fan working point with different control strategy of looping duct layout

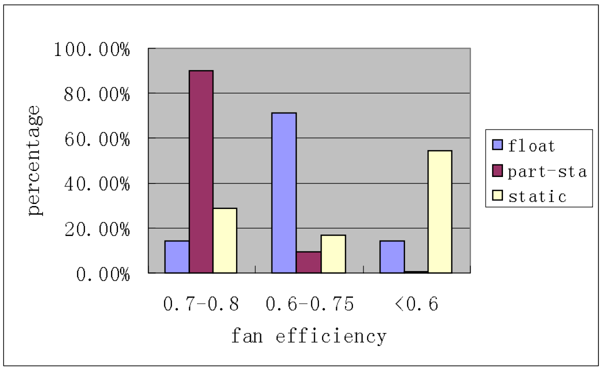



Figure 12: Fan efficiency distribution of different control stategy

The fan efficiency of this looping duct is similar with the tree duct. In Figure 12, the static control method with the static pressure point setting at fan export and the float pressure control method have the large high efficiency percentage than the method setting static point at the two-part of the whole duct.

Are there some difference between with the tree and looping duct layout? Figure 13 give us the answer. Using the float and part-static pressure control method, fan energy of the looping duct layout is little than the tree duct, but using the static pressure control with the static pressure point setting at fan export, these two kind methods have the same energy consumption.

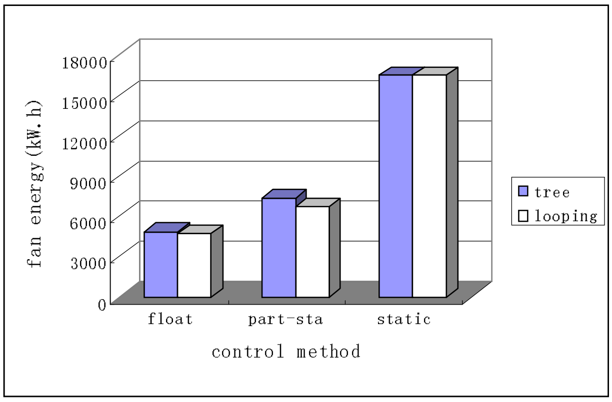



Figure 13: The difference of tree duct and looping duct layout with three control method

Although the fan energy of tree or looping duct with the static pressure point settign at fan export is same, they have some difference.

We research the fan energy using efficiency of these two duct layouts. The efficiency is defined in the following formula.

$$\eta_{fan} = \frac{E - \sum G_i \Delta P_i}{E} \qquad (3)$$

Where $E$ is the fan energy consumption of the whole year.

$G_i$ is the supply air volume of each VAV box.

$\Delta P_i$ is the pressure loss of each VAV box.

Table 2 shows the fan energy using efficiency of tree and looping duct layout. With the building refers in above paragraphs, the looping duct layout has the low efficiency than the tree duct layout. That is to say most of the fan energy was consumes at the terminal VAV box, so in this building, if the designer chooses the static control method, he should chooses the tree duct layout. This result is not always right, it is related with the different project.

Table 2: Fan energy using efficiency of looping or tree duct layout for static pressure control method

| | Looping | Tree |
|---|---|---|
| $G_i \Delta P_i$ | 11395.7 | 8902.6 |
| $E$ | 16452.6 | 16452.6 |
| $\eta_{fan}$ | 30.7% | 45.9% |

## CONCLUSIONS

1. Using simulation method can solve many problems for VAV system analysis.

2. Three kinds of fan speed control strategy are different in fan pressure head, fan rotation speed, fan running efficiency and fan operation energy.

3. The static pressure control method with static pressure point setting at the fan export implement easily, but when the supply air volume decrease, the fan pressure head will much larger than the VAV system needs, this part surplus energy becomes the terminal noise. This kind of method isn't a good method. When the static pressure point move from the fan export to the two-part of the whole supply air duct, the situation become better, but there are also surplus fan energy.

4. The most energy-saving fan speed control strategy is the float pressure control method. It only consumes 30% fan operation energy of the static pressure control method.

5. With the same control method, the different air duct layout may influence the fan energy consumption and the fan energy using efficiency.

6. VAV systems researcher should find some manners to help the float pressure control method step into the practical application.

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