THERMAL ENVIRONMENT OF OUTDOOR UNITS OF VRV SYSTEM IN HIGH-RISE BUILDING

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ABSTRACT

Variable Refrigerant Volume(VRV) air-conditioning system is more liable to meet thermal environment problem than other systems such as split-type air-or window-type air-conditioner because its capacity of outdoor unit is much higher. When used in high-rise building, hot air dissipated by the outdoor units will induce buoyant airflow and increase the working temperature of units at high floor when these heat can not be dispersed in time. High working temperature could not only degrade the total efficiency, but also cause stoppage of the system. To investigate the influencing factors of outdoor units of VRV system, Computational Fluid Dynamics (CFD) simulation and field test were carried out. Factors such as units combiniation and capacity, building height, set method, structure of the building and special places et al. were discussed. Suggestions for design and installation were given.

KEYWORDS

Thermal environment, CFD simulation, VRV system, High-rise building

INTRODUCTION

VRV air-conditioning system, sometimes called multi-connected air-conditioning system, is widely used in China in recent years. Different from its predecessor, split-type air-conditioner, the VRV system is composed of one outdoor unit and several indoor units. It has many advantages and can find its way whether in residential or commercial buildings.

Similar to other systems use air-cooled condenser, thermal environment of outdoor units of VRV system must be considered for proper operating and energy efficiency. In summer, outdoor condensers will warm up the air around and form a “mini thermal island”, which could increase the working temperature of itself or units around. Situation will become worse if many outdoor units set closely or in high-rise buildings.

Outdoor units of each floor are often set at same place in high-rise building. Heat given up by the condensers will induces a buoyant airflow. Since the total heating power of each floor is usually about several hundred kWs, working temperature of the outdoor units will increase to a considerable degree if this quantity of heat can’t be dispersed effectively. Because temperature increases along the height of the building, it will affect the efficiency and capacity of the air-conditioning system at the upper floors. In some extreme condition, whem condenser on-coil temperature higher than 43˚C, abnormal refrigerant working pressure may trigger the pressure protection and stop the compressor. Situation is worse if outdoor units are located in the place with poor ventilation such as recessed place or light well. As the widely use of the system in high-rise building, condenser heat dissipation problems are sometimes reported and must be considered in design stage.

The most effective method to study this problem is CFD method, which is used to analyse the complex phenomena of flow problems.

Current research mainly focus on split-type air-conditioner and window-type air-conditioner. Because capacity of these units is relatively small, thermal enironment of outdoor units will become worse only when they are stacked in recessed space or plant room.

For split-type air-conditioner, when installed in building re-entrant, height of building (Chow and Lin 1999), shape of re-entrant (Chow et al. 2000) were considered in affecting the units performance, an energy evaluation model was also used together with the CFD method in the latter.

The effects of condensers installed in the stacked air-conditioning plant rooms of a high-rise apartment building were studied numerically(Choi et al 2004). Performance of the condensers was evaluated using the Coefficient of Performance (COP) and Condenser Group Performance Indicator (CGPI) parameters. Effect of wind direction, wind velocity, and the arrangement and location of the condensers were investigated.

For window-type air-conditioner in recessed space of high-rise residential building, influence of height and units location (Bojic et al. 2001), depth of recessed space (Bojic et al. 2002) to temperature and flow field have been taken into account.

Content of this paper comes from series research on thermal environment of VRV system, including theory anlaysis, CFD simulation and field test, mainly to draw a outline of our research and give some advices for system design and installation.

THERMAL ENVIRONMENT OF VRV SYSTEM

VRV system is different to other air-conditioning systems in many aspects, so it’s necessary to analyse and evaluate the thermal environment separately to ensure a normal and high efficiency operation.

Capacity of the unit

Usually, capacity range of single unit of VRV system is 4-64HP, which is far larger than split-type and window-type air-conditioner. Generally, heat released by an unit of 20HP is about 73kW on standard condition. The vast heat dissipating capacity makes its thermal environment more liable to get worse.

Installation of the outdoor unit

Outdoor units can be installed on the ground or flat roof, but when in high-rise building, units are often set in a plant room with one side open to the outside at each floor because of the length limit of refrigerant piping. So plant room must be well ventilated, and influence of lower units on upper ones must be considered.

Characteristics of the outdoor unit capacity

COP, which is the ratio of the unit cooling capacity to the over all power input, is often unsed to describe the energy performance of an air-conditioner. COP of a split-type unit varies with its operating conditions. An air-conditioner performs better at higher room temperature T_r and lower condenser on-coil temperature T_o. At a given room temperature, the COP of a split-type unit can be calculated by

$$COP_{T_r} = a - bT_o \quad (1)$$

Where a and b are constants.

Statistic alanalysis (Chow et al. 2000) applying to catalogue data of several commercial products shows that when T_r is 25˚C

$$COP_{25} = 5.153 - 0.0738T_o \quad (2)$$

Coefficient of determination of this linear regression is 0.9915, applies well in the range of T_o from 25˚C to 45˚C for single speed units.

But for VRV system, ratio of total horsepower of combined indoor units to horsepower of outdoor unit must be considered additionally. This ratio varies from 50% to 130% for most products.

When capacity ratio of indoor units and outdoor unit is 100%, room wet-bulb temperature is 19˚C, data of one product can lead to:

$$COP_{19} = 8.1384 - 0.1302T_o \quad (3)$$

Coefficient of determination is 0.9832, range of T_o is from 10 ˚C to 39 ˚C. Data from 40˚C to 43˚C or high are not available.

COP value of VRV system is high than split-type and window-type air-conditioner under same condition. Further more, its capacity only has little reduction with the increase of condenser on-coil temperature. But, similar to other air-conditioner, COP droppes about 10% when outdoor temperature increase from 35˚C under the standard condition to 39˚C. COP under higher temperature may be even lower, which will weaken the performance of VRV system even it can still operating.

So, purpose of thermal environment research is control the working temperature of outdoor units as low as possible, not only for avioding the pressure protection but for better energy efficiency.

To evaluate and improve thermal environment of outdoor unit, series study were carried out, including CFD simulation of a ideal model and several real projects, field test of a project. The following report some findings and results.

SIMULATION

Actual operating condition of VRV system and outdoor climatic conditon is hard to predict and control, so simplifications and assumptions must be adopted to obtain a computable model, including:

1. All units operating under standard condition;
2. The walls are flat, without any openings;
3. Heat transfer through the wall is negligible;
4. Effects of solar radiation is negligible;
5. Temperature gradient along height of the wall is negligible;
6. Outdoor temperature and air movement is steady if considered.

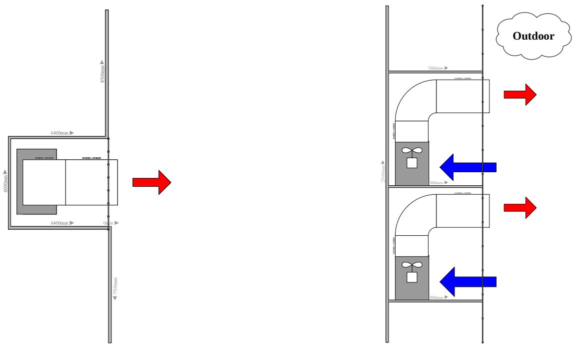
The standard $k-\varepsilon$ model is adopted as the turbulence model. Flow is set to be steady and incompressible.

Outdoor temperature is set to 35˚C.

The ideal model

The ideal model concerns the most common install location, i.e. in the plant room of each floor. The building is 100m high, with story height of 3.3m.

Exhaust air is induced to outdoor by a short duct, fresh air come into the plant room through the shutter inlet at the side wall. Installation and air flow direction is shown in Figure 1.



(a) Plan view (b) Section view

Figure 1 Schematic plan of the outdoor units

Four kinds of outdoor units are selected according to property of the model, application frequency et al. Parameters of the units are listed in Table 1.

Table 1 Conditions of outdoor units

MODEL	5HP	10HP	16HP	20HP
Heat dissipation rate (kW)	17.2	35.4	57.1	72.5
Air discharge rate (m^3/s)	1.45	2.87	4.63	5.73

Size of outlets are selected to ensure that they all have same height and their air speed about 4.1m/s.

In a case, each floor has the same unit(s) installation.

When only one unit is installed per floor, environmental temperature of the outdoor units varys according to the floor and the capacity is shown in Figure 2.

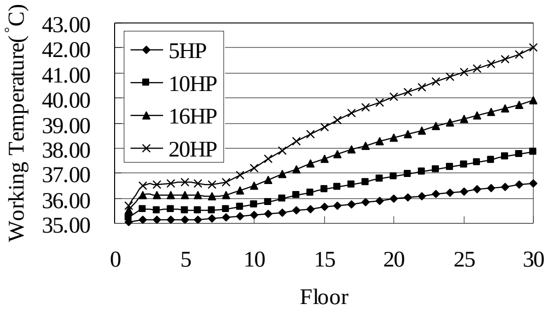


Figure 2 Working temperature of the outdoor units

From the curves it can be seen that temperature of first floor is close to the ambient temperature, then increases with the rise of the floor, units with higher capacity increase more quickly. No unit exceed the required temperature range.

One phenomenon must be mentioned is that curves between 2~7 floor is nearly horizontal, maybe it's because that the increased temperature enhanced the natural convection, cool air aroudn supplys quickly to keep the heat dissipation and disperse in balance in a certain range.

Situation is complicated when two units put side by side on each floor. To save the length, only general results are listed here.

Usually, the unit with high capacity has the high temperature on the same floor; the two units has big temperature difference when difference of their capacity is high; when two combinitions' total capacity is close, the one with less capacity difference has better thermal environment in total, for example, the combination of 16HP+16HP is better than 10HP+20HP even its capacity is a bit high.

When three units are put together, the one in the middle has the highest temperature independent to its capacity. More units of high capacity together in one floor in not recommended.

Increment of the outlet air speed can help the heat disperse quickly, but resistance of the duct must be controlled to ensure the required air rate. The fan with high pressure can support high outlet air speed.

Real projects

Simulation of real projects can also obtain results similar to the ideal model except the thermal environment also affected by some special factors such as location of the units, building outline, scheme of air outlet and inlet, units combination, et al.

Generalized from tens of real projects, following items should be remarked:

1. Lengthen gaps between units will make them work better;
2. Structure of the building should be used to produce good heat dispersion and avert back flow;
3. when installed at the corner of the building, setting inlet and outlet at different side is recommended;
4. Recessed place is not advisable especially when direction of the outlet flow isn't faces outside. Units set near outside have better working condition than inside ones;
5. Light well should be avoid for outdoor units installation cause the thermal environment will become worse in most circumstances.

There are two sources of the force to disperse the heat, one is the condenser fan of the outdoor unit, which influences the outlet air speed, fan power of certain product is usually fixed, the other is the heat pressure caused by the temperature difference.

Increased heat discharge can raise the temperature, then speed up the heat disperse. But when heat discharge reaches to a limit corresponding to the pressure protection temperature, the force will not increase any more.

Each position has a capacity limit of contained outdoor units. This limit is relatively low for recessed place and light well which should be avoided if possible.

FIELD TEST

Overview

Field test was carried out to verify the numerical method and find out the working environment of the outdoor units in actural condition. The project selected is Chongqing International Trade Centre.

Chongqing is well known for its hot weather, mean annual wind speed is 0.9-2.0m/s, high temperature and high rate of still wind makes thermal environment of outdoor units more easy to get worse.

The building is composed of a podium and two towers. The podium part is 1~9 floor, the tower part is 10~39 floor. Test is carried out in one tower.

Two units of 10 HP is installed in the plant room per floor as is shown in Figure 3. Scheme of air outlet and inlet is same to the ideal model.

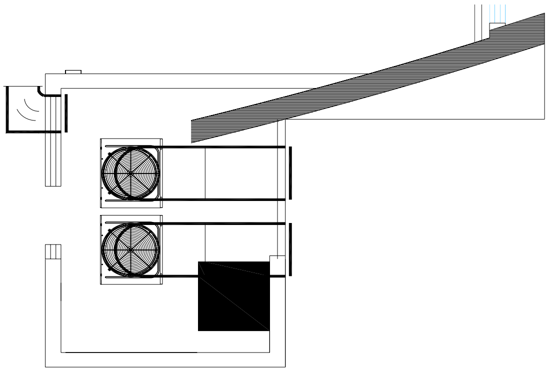


Figure 3 Plan of plant room at typical floor

Air speed and temperature ambient and in the plant room of each floor is tested by portable type TSI Model 8386 multi-parameter ventilation meter. Distribution of air speed of specific floor is tested by KANOMAX Model 1550 multi-channel airflow analysis meter with 0965-08 probes of hot sphere anemometer, distribution of temperature is tested by copper-constantan thermalcouples.

Results

The test is carried out in August 30 2005, weather data of that day is: mean temperature is 24˚C, not as hot as usual, wind speed is 0.28 m/s.

Test results of each floor shows that ambient temperature and air speed only has little fluctuation: range of temperature is 23.7-25.9˚C, high values were obtained in the afternoon; range of air speed is 0-0.4m/s. The data doesn't show obvious trend in varying with the change of the floor.

Data inside the plant rooms of some floors are break because the air conditioning system were under debug phase and some outdoor units can't work properly, but temperature increases obviously with the continuously rised floor. For example, temperature data in the plant rooms of 21-23 floor are 27˚C, 31.8˚C, 33.5˚C separately.

Horizontal distribution out of the plant room and vertical distribution in the plant room of the 23rd floor is tested. The horizontal plane is 1m high from the floor and the vertical plane is 0.1m from the front grille of the outdoor units. Each plane is composed of 3 rows of test points. Space length of the 10 points at the same row is 0.1m. The distance from the rows to the exterior wall are 1.0m, 2.3m and 3.0m of the horizontal plane. The height of the rows are 0.4m, 0.8m and 1.2m of the vertical plane.

The temperature data is shown in Figure 4 and Figure 5. Where the No. 1 test point locates at the upper side and No. 10 test point at the down side if seen from Figure 3.

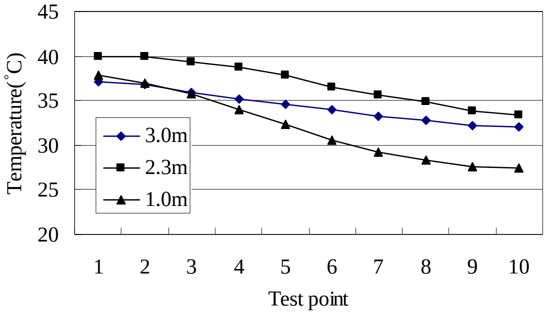


Figure 4 Tested temperature distribution outside of the plant room

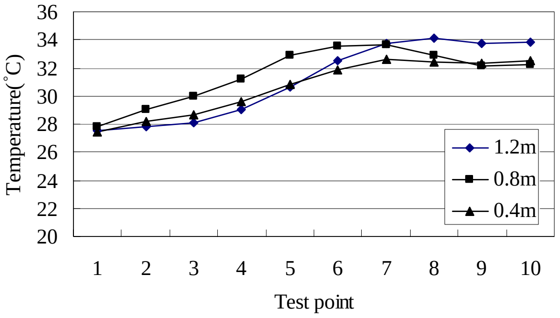


Figure 5 Tested temperature distribution inside of the plant room

Mean temperature outside and inside of the plant room is 33.5˚C and 31.1˚C separately.

Additional simulation

To make up the limitation of the field test and reveal more detail of the flow, CFD simulation is carried out. Model is built according to the field condition.

To compare with the field test, simulation results at the same points with the field test are shown in Figure 6 and Figure 7.

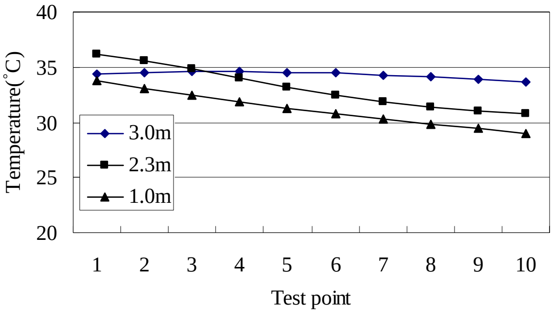


Figure 6 Simulated temperature distribution outside of the plant room

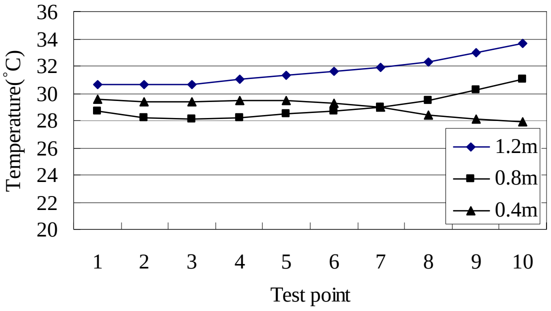


Figure 7 Simulated temperature distribution inside of the plant room

It can be seen that simulation results agree well with the field test in trend.

Mean temperature outside and inside of the plant room is 32.7˚C and 30.0˚C separately.

It's similar for air speed, and the deviation between test and simulation data is somewhat high.

Temperature and air speed data are low compare with the test data at corresponding points, this may be caused by omission of some factors such as solar radiation and airflow outside in the simulation.

Influence of the shutter

It's found by the test and simulation that temperature data are higher than expected value. Thermal environment became worse even at the lower floor. Primary analysis reveals that this may be caused by the change of shutters during construction.

The designed shutter is used for air discharge, its fin is horizontal with 10˚ incline, which can ensure effective air discharge and prevent the rain from entering at the same time. But the shutter is replaced by normal rainproof shutter in construction. The vertical fin of the shutterwill then block the outflow of the hot air and increase the temperature in the plant room.

To evaluate the effect of the shutter, additional simulation has been carried out. Two cases were added in addition to the original one, one removed some fins to double the gaps of the shutter, the other one removed all the fins.

Only three floors are selected to simulate, results of the calculated working temperature is shown in Table 2.

Table 2 Calculated working temperature

FLOOR (UNITS)	ORIGINAL (˚C)	DOUBLE GAP (˚C)	NO FINS (˚C)
3(left/right)	30.57/30.40	28.48/28.26	26.92/26.34
2(left/right)	28.70/29.25	27.86/28.06	26.43/26.41
1(left/right)	26.08/27.13	26.10/26.29	25.27/25.39

Looking along the direction of the outflow, left unit is the upper one in Figure 3.

From the table it can be seen:

1. Units temperature is higher at higher floor in any cases;
2. Temperature of the two units at same floor has some difference because model of the plant room and units are not symmetrical;
3. Temperature has a drop after gap of the fins is doubled. It decreased much in higher floor;
4. Working temperature is the lowest when all fins are removed.

It can be concluded that the shutter did influenced thermal environment of the plant room. As a solution, some fins are removed considering the external appearance and ventilation effect.

Now the project was finished and survived the hot summer of Chongqing in 2006, all outdoor units work normally even in the hottest days. Although the energy efficiency in operation needs additional research.

CONCLUSION

Thermal environment of outdoor units of the VRV system will become worse if not properly designed or installed especially in high-rise building. It can affect not only the normal operating but also the energy efficiency of the system. By means of CFD simulation and field test, this problem was investigated, suggestions were given for system design and installation.

Influence of units capacity, units combiniation and building height is quantitatively analysed by an ideal model, the data can be used for a basic estimate before system design.

More factors were considered in real projects. Set method, structure of the building and special places were discussed.

By field test, CFD method was verified and some features in actual running were found. Effect of shutter was analysed in detail by the CFD simulation.

To save the length, other factors such as speed and direction of the wind, solar radiation, load ratio of the outdoor units et al. were not discussed here.

Total performance of the outdoor units can be calculated if only capacity characteristics at high temperature is available. That will be more useful in project comparison and energy efficiency evaluation.

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