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Study on the uneven distribution of vertical space humidity in a rocket testing workshop

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Abstract. In view of the problem of inconsistent air-conditioning delivery and uneven distribution of vertical space humidity in a rocket testworkshop at a coastal launch site, this paper analyzes the cause and mechanism of the problem based on the characteristics of high space air distribution, test plant structure and air-conditioning system. And puts forward the specific measures such as adjusting high-rise space air delivery target, optimizing the airconditioning control strategy and improving the unit's dehumidification capacity. These measures provide support for the solution of the problem and the optimal design and transformation of air-conditioning.

1. Introduction

A coastal launch site belongs to a typical tropical marine climate, with an annual average temperature of 24.8 °C and an average humidity of 87.2%. The perennial high temperature and humidity climate environment poses a severe challenge to the environmental protection of rockets, satellites and other spacecraft and other types of equipment. As the most important means of environmental protection, air-conditioning system provides long-term environmental protection work for spacecraft, rockets and other precision equipment and personnel in the field.

A rocket test workshop provides site, equipment support and environmental protection for the vertical assembly and various tests of a rocket. The hall of the test workshop is about 50m long, 30m wide and 100m high, which belongs to the typical large space. Because of the large vertical space, it is easy to produce a vertical temperature gradient and the large proportion of the outer wall of the large space, the air distribution of air-conditioning and the guarantee of temperature and humidity environment in large space have certain challenges. With the rapid development of construction industry, the air-conditioning design and air distribution of large space has become a research hotspot. In 2012, Wang X. and others successfully designed the displacement ventilation air-conditioning of a membrane structure roof exhibition hall in Shanghai World Expo by using Chen's displacement ventilation CFD simulation formula, and achieved good results[1]. In 2017, Jia Zh. K. and others targeted the National Convention and Exhibition Center. The design and simulation of the air supply system in the super large exhibition hall are carried out, and the conclusion that the upper air supply system should be adopted is drawn[2]. In 2018, Pan D. M. and others studied the simulation of air distribution of air-conditioning in large space, and gave the method to improve the simulation accuracy[3]. In 2018, Weng J. T. and others tested and analyzed the indoor thermal environment of a terminal building in winter, and put forward suggestions for optimization and improvement[4].

The air-conditioning of the test plant adopts layered air-conditioning and side supply and side return mode, but during the task support process, it is found that there are some problems such as

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inconsistent humidity distribution and air supply parameters of the air-conditioning unit, which has a negative impact on the environmental protection of the rocket test and the normal operation of the air-conditioning unit. In this paper, the above problems are analyzed and studied, and targeted solutions are put forward.

2. Testing the basic situation of air-conditioning in factory buildings

2.1. Air-conditioning system of factory building

The air-conditioning system of a rocket test workshop is mainly used to ensure the temperature and humidity of the environment in the test hall, and its process requirements, system composition and control mode are as follows:

1) Process requirements. Stratified air-conditioning, side to side return mode, fresh air ratio 10%. The temperature in the control hall is 16~28°C, and the relative humidity is \leq 70%.

2) System composition. The air-conditioning system in the hall consists of 12 subsystems, with air volume of 15000m³/h, each unit has the same function section. Each unit and supporting pipeline form an independent and complete subsystem, and each unit guarantees the vertical space of the hall in layers according to its location. Each set of subsystems is composed of fresh air section, primary effect filter section, return air section, front surface cold section, rear surface cold section, heating section, air supply section, medium effect filter section, air supply pipe, spherical tuyere, louvered return tuyere, return air pipe and other connections.

3) Temperature and humidity control mode. Each unit has an independent front-end controller to complete the measurement and transmission of the parameters of each measurement and control point, send the data to the central console, and receive the instructions from the central console and execute them, so as to realize local/remote automatic/manual control. Each unit takes its own return air temperature and humidity as the control goal. In addition, the air-conditioning system can be fully automatic operation mode, front and rear surface cold water valve opening, electric heating input and so on are controlled by the automatic control system. Manual control mode can also be used to set the required input for part or all of the equipment in the unit manually.

The front surface cooling section of each unit is mainly responsible for dehumidification, and the rear surface cooling section is mainly responsible for cooling. In addition, because the vertical hall air-conditioning system is comfortable air-conditioning, the design pays attention to the adjustment of the hall temperature, and there is no dehumidification equipment except for the front surface cooling section, so the humidity adjustment ability and accuracy are relatively weak.

2.2. Existing problems

In the process of mission support, it is found that the air supply parameters of each air-conditioning unit are inconsistent and the humidity distribution of vertical air-conditioning in the hall is uneven in the automatic control mode of the hall air-conditioning system.

1) Each air-conditioning unit uses the same (24 °C, 50%) return air target, and its supply air temperature and humidity has a big difference (15 °C, 85%) and (25.5 °C, 65%).

2) The humidity distribution in the vertical space of the hall is uneven, and the humidity in the upper floors, especially those above 10 floors, is often above 70%, occasionally higher than 75%, which exceeds the upper limit of humidity required by the product side.

3. Analysis of construction difficulties problem analysis

3.1. Inconsistency of air supply parameters of air-conditioning units

3.1.1. Description of issues. During a rocket launch mission, the system found that when the return air target of each air-conditioning unit is the same (24°C, 50%), the temperature and humidity of each air-conditioning units are quite different, KT-F1B-1, KT-F3B-3, KT-F7B-4, KT-F9B-4 units are heated,

Table	1. Air paramet	ters of vertical h	all air-conditioni	ing in automatio	c control mode	
unit	air supply	parameters	return air	parameter	safeguard area	
um	T (°C)	H (%)	T (°C)	H (%)	salegualu alea	
KT-F1B-1	25.7	64.6	23.5	68.6	West side, 1F-2F	
KT-F1B-4	15.0	85.6	24.2	67.8	East side, 1F-2F	
KT-F3B-3	24.2	64.3	23.8	68.3	West side, 3F-4F	
KT-F3B-4	23.4	69.9	24.0	68.8	East side, 3F-4F	
KT-F5B-3	18.0	75.6	24.1	68.1	West side, 5F-6F	
KT-F5B-4	18.7	77.0	24.0	70.2	East side, 5F-6F	
KT-F7B-3	18.0	86.8	24.0	70.8	West side, 7F	
KT-F7B-4	24.5	65.3	23.8	70.8	East side, 7F	
KT-F9B-3	16.5	84.5	24.2	72.4	West side, 8F-9F	
KT-F9B-4	25.6	57.8	22.7	72.0	East side, 8F-9F	
KT-F11B-3	16.7	83.8	24.4	74.2	West side, 10F-11F	
KT-F11B-4	17.0	74.4	24.6	76.7	East side, 10F-11F	

and KT-F1B-4, KT-F5B-3, KT-F5B-4, KT-F7B-3, KT-F9B-3, KT-F11B-3 and KT-F11B-4 units are cooled, and the parameters are recorded as shown in Table 1.

3.1.2. Cause analysis. Each air-conditioning system takes the temperature and humidity of the return air in its own return air system as the control point, and the temperature of 24 °C and humidity of 50% as the target of PID adjustment. First of all, in terms of temperature, when the system detects that the return air temperature exceeds 24 °C, it will gradually increase the opening of the cold water valve in the rear surface cold section, increase the cooling ability and reduce the supply air temperature. On the contrary, when the return air temperature is lower than 24°C, the automatic control system will gradually reduce the opening of the cold water valve in the rear surface cold section and increase the supply air temperature.

In terms of humidity, when the system detects that the return air humidity exceeds 50%, it will gradually increase the opening of the cold water valve in the front surface cold section, increase the dehumidification capacity and reduce the supply air humidity. On the contrary, when the return air temperature is lower than 50%, the automatic control system will gradually reduce the opening of the cold water valve in the front surface cold section, reduce the dehumidification capacity, and improve the humidity of the supply air.

Although the air supply of each air-conditioning unit is sent to the same hall, due to the different installation positions of the return air temperature and humidity sensors of each unit and their own measurement errors (the measurement accuracy of the sensors: temperature ± 1 °C, humidity $\pm 3\%$), the measured return air temperature and humidity of each unit are slightly different. Because the return air temperature measured by each unit is higher than or below 24 C, it also leads to the difference of temperature and humidity of the supply air. With the manual control mode, and the opening degree of the cold water valve of the front and rear stages of each air-conditioning unit is manually (100% of the front stage and 50% of the rear stage), and the opening degree of the rear stage valve is fine-tuned according to the feedback situation, and the parameters are shown in Table 2 after stabilization.

Tabl	e 2. Air param	eters of vertical	hall air-condition	ning in manual	control mode	
mait	air supply	parameters return air parameter		parameter	cafaguard area	
umi	T (°C)	H (%)	T (°C)	H (%)	saleguard area	
KT-F1B-1	20.8	69.5	22.6	67.7	West side, 1F-2F	
KT-F1B-4	19.9	74.7	23.6	67.7	East side, 1F-2F	
KT-F3B-3	19.9	71.7	23.2	67.3	West side, 3F-4F	
KT-F3B-4	18.3	73.7	23.4	67.5	East side, 3F-4F	
KT-F5B-3	18.9	69.3	23.9	66.7	West side, 5F-6F	
KT-F5B-4	19.8	72.0	23.9	68.5	East side, 5F-6F	

KT-F7B-3	17.7	77.7	24.0	69.5	West side, 7F
KT-F7B-4	17.1	74.3	23.5	67.7	East side, 7F
KT-F9B-3	18.5	75.8	24.6	72.0	West side, 8F-9F
KT-F9B-4	17.8	73.0	22.9	71.6	East side, 8F-9F
KT-F11B-3	19.3	74.9	25.4	75.5	West side, 10F-11F
KT-F11B-4	19.4	81.0	25.5	76.9	East side, 10F-11F

It can be seen from Table 2 that under the control mode of manually setting the opening of the surface cooling valve and the input ratio, the air supply parameters of each air-conditioning unit are relatively consistent, and there is no case of heating and cooling of the unit.

3.2. Uneven distribution of humidity in vertical space

3.2.1. Description of the problem. From the beginning of the joint training task, there has been a long-term problem of uneven humidity distribution in the vertical space of the factory building, and the humidity in the high-rise space is obviously higher than that in the low-rise space. As can be seen from Table 1 and Table 2, the return air humidity in the lower space of 1-5F is 65-68%, and that in the upper space of 6-12F is 69-77%, especially in the space above 10F, the humidity is often higher than 70%.





Figure 2. Humidity guarantee of X floor of a factory hall in a first flight mission

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It is observed that the air-conditioning system can control and maintain the temperature accurately, but it can not control the environmental humidity well, and the humidity in the hall often reaches or even exceeds the upper limit of 70%.

3.2.2. Cause analysis. In view of the uneven distribution and high humidity in the vertical space of the vertical hall, the main reasons are as follows:

1) The humidity control ability of air-conditioning units is weak. The air-conditioning system in the vertical hall of the rocket test building is comfortable air-conditioning, which pays attention to the adjustment of the temperature in the hall, and has weak ability to regulate and control humidity. The poor control ability is reflected in two aspects, the first is poor control accuracy, the system does not have other humidity precision control dehumidification equipment except the front surface cooling section with surface cooling dehumidification function, its humidity regulation ability and accuracy are relatively weak. Secondly, the dehumidification capacity is weak, the target humidity of return air set by air-conditioning unit is 50%, when the opening degree of cold water valve in the front table cold section is 100%, the return air humidity of unit is always higher than 50%, most of the time between 60-70%.

In addition, there is no air-conditioning in the 12-13F space, leading to the KT-F11B-3 and KT-F11B-4 units designed for the 10-11F is more difficult to guarantee 10-13F.

2) The control strategy of air-conditioning temperature and humidity needs to be optimized. In the control strategy of cooling and dehumidification in the vertical hall of the rocket test building, the temperature adjustment is emphasized, which leads to the failure of the dehumidification function of the rear stage table cooling of the unit. In the automatic control mode, the post-stage table cooling section is only used for cooling, after the temperature of the hall meets the requirements, the air can not be dehumidified after dehumidification treatment of the pre-stage table cooling section, even if the moisture content of the air can not meet the requirements. In the case of weak dehumidification capacity of the front-stage table cooler, it often occurs that the hall humidity is still higher than the target humidity after 100% of the front-stage table cooler is put into operation, and the back-stage table cooler can not be fully utilized. If the control strategy can be optimized, the target temperature and humidity can be balanced, and the dehumidification capacity of the rear surface cooler can be maximized under the condition of allowable electric heating and heating, the humidity of the hall can be reduced to a certain extent.

3) The hall of the test workshop is not sealed well. After inspection, the opening cracks and holes above the door of the test workshop, the hall and the horizontal test workshop are connected, the damaged doors on the 13th floor (the whole wall outside the room is a shutter fence, which is directly connected with the outside) and the window opening behavior of the staff in the test rooms on each floor will lead to the decline of the sealing performance of the hall.

The test plant is facing the sea, in the tuyere position, its south side, southeast, southwest side of the long-term strong wind. The results show that when the wind speed is more than 4m/s, the generated wind pressure exceeds the positive pressure of the clean workshop l0Pa, and when the wind speed reaches 11m/s, the wind pressure reaches 50Pa. In the case of poor sealing performance of the hall, the hall will lose positive pressure, resulting in the rapid influx of high temperature and humidity air into the hall, which will have a negative impact on environmental protection, and will also lead to the difficulty of maintaining temperature and humidity in the upper space of the hall.

4. Research on Response Measures

According to the current situation and cause analysis of inconsistent air supply parameters and uneven vertical space humidity distribution of air-conditioning units, the corresponding measures are formulated as follows:

1) Timely adjusting the target of air supply guarantee in high-rise space. The phenomenon of cold air falling and hot air rising is caused by the large temperature difference and long jet flow in the hall,

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which leads to the uneven distribution of temperature and humidity in the vertical space[5, 6]. Therefore, according to the actual temperature and humidity of the high-rise space in the hall, the air supply guarantee goal of the high-rise space can be adjusted appropriately when the capacity of the air-conditioning unit is allowed, so as to reduce the temperature and humidity of the high-rise space environment.

2) Optimizing the temperature and humidity control strategy of air-conditioning. At present, there is a problem of focusing on temperature and light humidity in the cooling and dehumidification control strategy of the air-conditioning system in the test plant, which leads to the failure of the dehumidification function of the unit's back-stage table cooling. Therefore, it is necessary to optimize the control strategy of temperature and humidity of air-conditioning units, balance the target temperature and humidity, maximize the dehumidification capacity of the rear surface cooler under the allowable heat of electric heating, and reduce the humidity in the hall.

3) Improving that measurement accuracy of return air temperature and humidity. A slight deviation in the measured return air temperature of each air-conditioning unit will lead to differences in the working state of each unit, so it is necessary to improve the measurement accuracy of return air temperature and humidity of each air-conditioning unit, so as to prevent the problem of inconsistent working state of the unit due to errors. The main measures are: first, increase the number of return air measurement sensors per floor air-conditioning units, using the average temperature and humidity as the control target parameters. Second, regularly calibrate the temperature and humidity sensors of the unit to ensure their accuracy.

4) Improving the dehumidification control ability of the unit. At present, besides the dehumidification function of the front surface cooler, there is no other humidity control equipment such as rotary dehumidifier, and the control ability of the air-conditioning unit is weak. Therefore, the follow-up need to be based on the actual needs of the air-conditioning unit equipment transformation, for its additional humidity control equipment.

5) Do a good job of sealing treatment in the hall of the workshop. At present, the problem of inadequate sealing in various situations of the factory building also leads to the uneven distribution of vertical space humidity to a certain extent, and the follow-up needs to strengthen the sealing treatment of the hall and the sealing inspection of doors and windows during the task.

5. Conclusion

Aiming at the problems of inconsistent air supply and uneven humidity distribution in a large space of a rocket test workshop, the mechanism of the problem was analyzed and studied. According to the actual situation of air-conditioning in the factory building, it puts forward some specific measures, such as adjusting the air supply target of high-rise buildings, optimizing the control strategy of airconditioning, improving the temperature measurement accuracy of return air and dehumidification capacity of units, which effectively improves the guarantee effect of air-conditioning, and provides support for the capacity improvement and transformation of follow-up air-conditioning units and the guarantee of rocket test environment for launch missions.

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