Research on the Influence of Valve Sensor Fault Based on Simulation

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Abstract: In the practical application of indoor air quality assurance system, it is difficult to detect the fault of air valves, CO2 sensors and other components, resulting in substandard air quality and increased energy consumption. In this paper, 16 fault conditions and 1 no fault condition were simulated by Simulink simulation software for primary return air conditioning system in summer, and a typical indoor air quality assurance system simulation fault characteristic table was obtained. It is found that PM2.5 sensor fault mainly affects indoor PM2.5 purification speed. The fault of a CO2 sensor affects indoor CO2 dilution and system energy consumption. Small resistance of return air valve increases system energy consumption. Small resistance of supply air valve, exhaust air valve and return air valve decreases the system's ability to control indoor pollutants.

1.Introduction

In recent years, with the improvement of living standards, people have paid more and more attention to the problem of air pollution [1,2]. In order to effectively maintain good indoor air quality, more and more people use sensors to monitor various indoor air parameters. Sensors can accurately and objectively monitor indoor air quality, so as to guide the HVAC system to carry out purposeful regulation of indoor air. However, in the process of regulation and control, if the sensor as the control basis or the valve as the control means fails, it will inevitably affect the energy consumption of the air conditioning system and indoor air quality.

Since the beginning of last century, there have been researches on fault diagnosis of indoor air quality assurance system at home and abroad. Du [3] proposed a fault diagnosis method for air conditioning system sensors. Faults include temperature, flow rate and pressure, and the fixed deviation of temperature sensor is ±10% and ±8%. The fixed deviation of flow sensor is ±10% and the drift slope is ±0.2kg/s/h; Pressure sensor deviation of 20% and drift slope of 30Pa/h. Ying Yan [4] proposed a fault diagnosis method based on distributed Boltzmann machine to realize the offset and drift fault diagnosis of sensors of air supply temperature, air mixing temperature, air supply volume and air return volume of air conditioner. Shiqiang Wang [5] proposed a distributed genetic algorithm, which can realize the fault detection and self-correction of pressure, flow and temperature sensors in distributed HVAC. Woo Seung Yun [6] proposed a data-driven fault diagnosis method for air processor, realizing the fault diagnosis of fresh air valve blockage, exhaust valve blockage, water system valve blockage and instability, heating coil surface scaling fault, and used ASHRAE RP-1312 experimental data to test the effect. Many scholars at home and abroad use MATLAB Simulink as a tool for modeling in the research process, and obtain the data set of the operating parameters of the fault system under the fault state through simulation, and build the data diagnosis method. Shaoyong Li [7] used MATLAB Simulink to model the fan coil system and used this model to complete the PID control optimization research of indoor temperature based on ant colony optimization algorithm, so as to improve the quality of indoor temperature control. Tom Marsik [8] used MATLAB Simulink to model an air-conditioned room equipped with a heat recovery device with particulate matter filtration function, and conducted simulation with the model, which proved that the device played a positive role in reducing energy consumption and improving indoor air quality.

As a simulation tool, MATLAB Simulink has been widely used in air conditioning systems. Many researchers at home and abroad have used Simulink as a tool to build reliable air conditioning system models, but they have not conducted modeling and simulation for buildings with indoor air quality assurance systems that take into account CO_2 and PM2.5 pollutants. Therefore, this paper uses MATLAB Simulink software to build a typical indoor air quality assurance system model. According to the common faults of indoor air quality assurance system obtained in literature research, the fault conditions are set, and the characteristic parameters of system operation are selected to analyze the influence of each fault on the CO2 dilution, PM2.5 purification and energy consumption performance of the system.

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2. Research Method

According to the literature research, the simulation experiment condition table was designed. The relevant parameters of the simulation room were determined, and the mathematical model of the main body, control and energy consumption system of the air quality assurance system was established. The simulation model of the typical indoor air quality assurance system was built by Simulink simulation software, and the fault and fault free conditions were simulated and studied. The variation of transport characteristic parameters in each working condition is analyzed.

2.1. Research Index

Indoor air quality assurance system mainly focuses on indoor pollutants such as CO_2, particulate matter and VOCs, among which CO_2 and VOCs pollution sources are indoor, and the control means are mainly diluted by outdoor fresh air. Meanwhile, some existing studies [9,10] show that the reliability of low-cost VOCs sensors still needs to be improved. Therefore, CO_2 is taken as the representative of the research; Generally, PM10 and PM2.5 are used to limit the concentration of particulate matter in indoor air. Here, PM2.5 with smaller particle size is selected as the research index. The fault may also affect the system energy consumption. If the fresh air valve is stuck, the system needs more load for hot and wet treatment of the fresh air. Therefore, this paper takes CO_2 concentration, PM2.5 concentration and energy consumption as research indicators to extract characteristic parameters of system operation, so as to describe the impact of faults on the system.

2.2 Model Building

After the mathematical model is established by Simulink tool, the calculation results can be simulated quickly and a large number of parameters of each point can be obtained for calculation and analysis, which is suitable for this study. Therefore, Simulink simulation software was used to build the simulation model of typical indoor air quality assurance system.

Simulink simulation requires deducing and establishing the relevant mathematical model, and then completing the construction of the simulation model according to the mathematical model. The mathematical model of the main part of indoor air quality assurance system is divided into fan system providing power, valve and conveying system regulating fresh air ratio, air filtration device and pollutant source system. Control system for valve and fan gear regulator. The energy consumption of indoor air quality assurance system is divided into fresh air energy consumption and fan energy consumption.

The main part of the typical indoor air quality assurance system is composed of air ducts, pipe fittings, valves and fans, indoor CO_2 purification module with pollution sources and purification and dilution mechanism, indoor PM2.5 purification module. The control system is composed of air duct parameter input module, fan controller, valve controller, fan speed regulation and valve opening signal conversion module. The energy consumption system consists of energy consumption modules, as shown in **Fig. 1**.

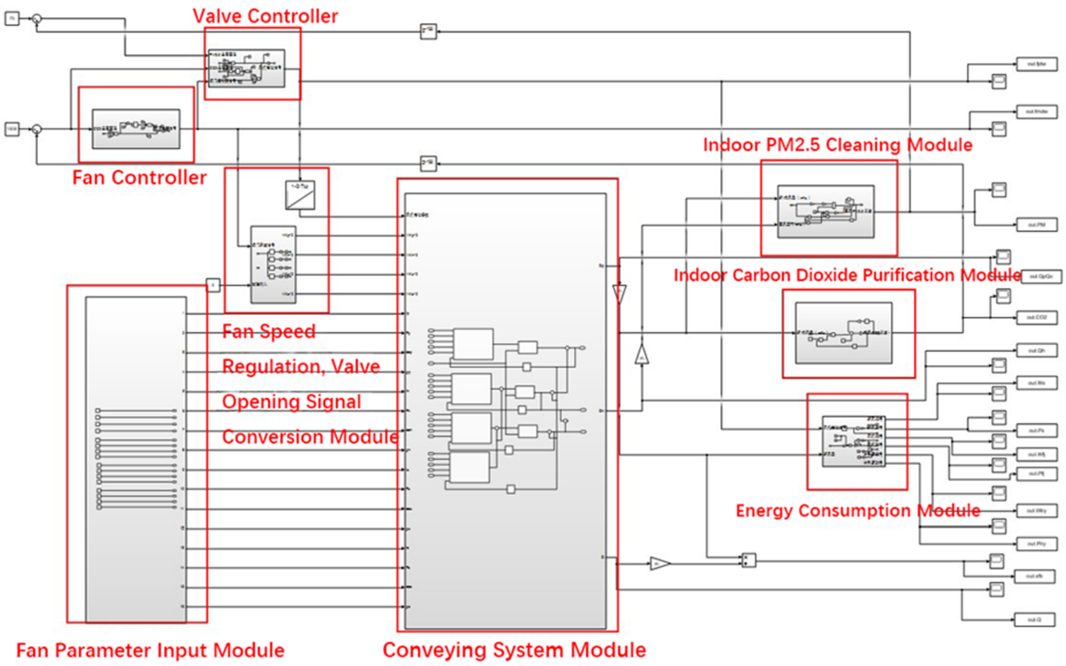

Fig. 1. Simulation model diagram

2.3 Modeling Scheme

This study selects a typical simulated room: an office room 3 meters long, 4 meters wide and 3 meters high. There are 3 office workers in the room, and the air supply is 180m³/h according to engineering experience. The concentration of CO_2 in the outdoor atmosphere is set to

400ppm, and the initial concentration of CO_2 is set to the standard limit of 1000ppm. The initial PM2.5 concentration is set to 500μg/m³ and the outdoor atmospheric PM2.5 concentration is set to 75μg/m³. In order to ensure the rapid control of indoor pollutants in the purification mode, a double-fan single-return air system is adopted.

The common fault is valve block. In view of this fault, simulated valve fault conditions are set for fresh air valve, return air valve, exhaust valve and supply air valve. The common faults of sensors are offset, drift and reduced accuracy. For the CO_2 sensor and PM2.5 concentration sensor of indoor air quality assurance system, set the fault condition of the simulated sensor. For specific design, as shown in **Table 1**:

Table 1. Simulation condition table

Number	Trouble location	Return air valve	Blow valve	New air valve	Exhaust valve
0	Standard operating condition	A			
W1	Small fault of blow valve	A	first gear	A	A
W2	Large fault of blow valve	A	third gear	A	A
W3	Small fault of exhaust valve	A	A	A	first gear
W4	Large fault of new air valve	A	A	third gear	A
W5	Small fault of return air valve	third gear	A	A	A
W6	Large fault of return air valve	first gear	A	A	A
W7	Large fault of indoor CO_2 sensor	A			
W8	Small fault of indoor CO_2 sensor	A			
W9	CO_2 sensor drift becomes larger	A			
W10	CO_2 sensor drift becomes smaller	A			
W11	The accuracy of CO2 sensor is reduced	A			
W12	Large fault of PM2.5 sensor	A			
W13	Small fault of PM2.5 sensor	A			
W14	PM2.5 sensor drift becomes larger	A			
W15	PM2.5 sensor drift becomes smaller	A			
W16	The accuracy of PM2.5 sensor is reduced	A			

To simplify the form, replace "Pollutant concentration control" with symbol "A"

3. Findings and Analysis

The diluting speed ratio (A_{vx}), purifying speed ratio (A_{vj}), fan two-stage running time ratio (A_t), fan energy consumption ratio (A_f), fresh air energy consumption ratio (A_x) and system energy consumption ratio (A_w) were selected to describe the fault operation characteristics of indoor air quality assurance system.

3.1 The Effect to CO_2 Dilution of each Fault

In addition to indoor PM2.5 sensor fault, valve jamming fault and indoor CO_2 sensor fault will affect the CO_2 dilution effect. From the range distribution of indoor CO_2 concentration, smaller supply valve and larger return valve will increase the range of indoor CO_2 concentration, while smaller exhaust valve and smaller CO_2 sensor will decrease the range of indoor CO_2 concentration. From the perspective of system control ability, larger supply valve, larger fresh air valve and smaller return air valve will lead to enhanced system control ability, while smaller exhaust valve will lead to weakened system control ability, and the degree of enhancement or weakening is different in each working condition. When the exhaust valve is too small and the CO_2 sensor is too large, the system cannot complete indoor CO_2 dilution, and the A_{VX} in fault condition fluctuates between 72.2% and 162.7%, as shown in **Table 2**.

Table 2. The effect to CO2 dilution of each fault in summer

Number	Avx(%)	Sensor CO2 concentration value	Actual range of CO2 concentration
W1	89.5	-	上升
W2	162.7	-	Approach 953ppm
W3	Can not be completed	-	Approach 1540ppm
W4	109.6	-	Approach 971ppm
W5	Not started	-	Approach 676ppm
W6	72.2	-	Rise
W7	Can not be completed	Approach 1054ppm	Decline
W8	152.7	915-1005ppm	Rise
W9	Can not be completed	It spirals out of control and keeps rising linearly	Approach 654ppm

Number	Avx(%)	Sensor CO2 concentration value	Actual range of CO2 concentration
W10	Not started	Linear continuous reduction	Approach 1588ppm
W11	CO2 fluctuates	Persistent jitter	Narrow down
W12	100.0	-	No significant change
W13	100.0	-	No significant change
W14	100.0	-	No significant change
W15	100.0	-	No significant change
W16	100.0	-	No significant change

Note: The data presented in percentage mode in the table is the ratio between the data in the current working condition and that in standard working condition. "-" indicates that the parameter is not affected by faults in the current working condition.

3.2 The Effect to PM2.5 Purification of each Fault

Except for the large blockage fault of the return air valve, all the faults will affect the purification effect of PM2.5. From the perspective of system control ability, smaller exhaust valve, smaller return air valve, smaller PM2.5 sensor, smaller PM2.5 sensor drift will reduce the system control ability, and the exhaust valve blockage small fault system control ability decreased the most, reduced to 56.5%. Large supply valve, large fresh air valve, large CO_2 sensor, and large CO_2 sensor drift increase the system regulation ability. Among them, large supply valve blockage increases the system regulation ability the most, rising to 125.3%. A_{vj} in fault condition fluctuates in the range of 56.5% to 125.3%, as shown in **Table 3** and **Fig. 2**.

Table 3. The effect to PM2.5 purification of each fault in summer

Number	Avj (%)	PM2.5 actual purification speed ratio (%)
W1	88.3	-
W2	125.3	-
W3	56.5	-
W4	102.7	-
W5	87.2	-
W6	101.8	-
W7	108.2	-
W8	97.1	-
W9	102.1	-
W10	97.1	-
W11	99.7	-
W12	71.9	100.0
W13	117.0	95.6
W14	85.1	100.0
W15	106.4	95.4
W16	100.1	99.4

Note: The data presented in percentage mode in the table is the ratio between the data in the current working condition and that in standard working condition. "-" indicates that the parameter is not affected by faults in the current working condition.

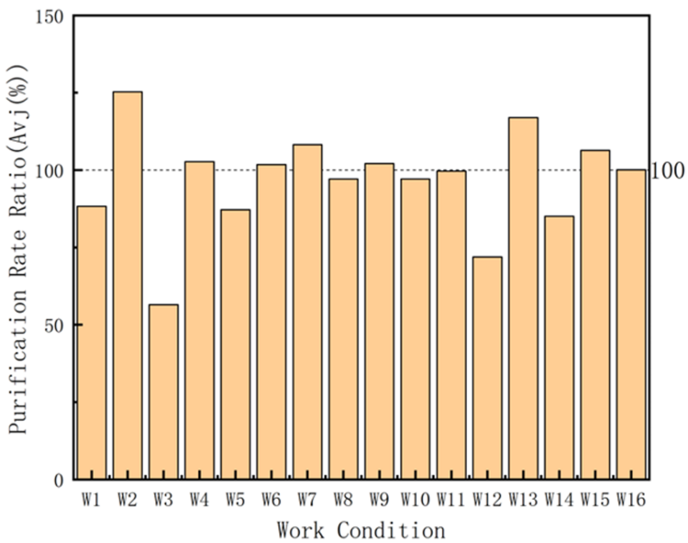

Fig. 2. The effect to PM2.5 purification of each fault in summer

3.3 The Effect to System Energy Consumption of each Fault

Except for the fault of indoor PM2.5 sensor precision reduction, other faults will affect energy consumption factors. Indoor PM2.5 sensor failure mainly affects the running time of the second gear fan. When the indoor CO_2 sensor drift is small fault, the system energy consumption is reduced to about 58%. When the indoor CO_2 sensor has a large fault, the system energy consumption increases the most, rising to about 234%. A_w, A_x, A_f and A_t fluctuates in the range of 57.9%-235.2%, 47.5%-261.6%, 90.3%-134.0%

and 35.8%-338.6% respectively under the fault condition, as shown in **Table 4**.

Table 4. The effect to system energy consumption of each fault in summer

Number	Aw (%)	Ax (%)	Af (%)	At (%)
W1	99.7	97.3	108.5	156.2
W2	101.6	104.5	90.3	35.8
W3	65.4	47.5	134.0	338.6
W4	101.5	102.4	97.9	88.0
W5	127.4	137.1	92.4	38.1
W6	100.2	98.0	108.7	157.3
W7	235.2	261.6	134.0	338.6
W8	62.7	54.9	92.4	46.5
W9	208.4	229.2	128.6	301.2
W10	57.9	49.1	91.5	39.6
W11	95.9	97.1	91.3	38.7
W12	100.7	100.5	101.4	109.7
W13	99.7	100.0	98.9	91.9
W14	100.2	100.1	100.3	102.4
W15	99.9	99.9	99.7	97.9
W16	100.0	100.1	99.9	99.4

Note: The data presented in percentage mode in the table is the ratio between the data in the current working condition and that in standard working condition.

4. Conclusion

In this paper, Simulink simulation software was used to design and build a typical indoor air quality assurance system model of a three-person office with a size of 3m×4m×3m. In summer, 16 fault conditions and 1 fault free condition related to indoor PM2.5 sensor, indoor CO_2 sensor and air supply valve, fresh air valve, exhaust valve and return air valve were simulated. The following conclusions are reached:

1) Sensor fault: PM2.5 sensor failure mainly affects indoor PM2.5 purification speed, but has no obvious effect on other parameters. In addition to affecting the dilution of indoor CO_2, the failure of CO_2 sensors also has a great impact on the system energy consumption. Large indoor CO_2 sensors and large indoor CO_2 sensor drift can increase the system energy consumption by 35.2% in summer. However, small indoor CO_2 sensors and smaller indoor CO_2 sensor drift will stabilize indoor CO_2 concentration above the limit value and deteriorate indoor air quality. At the same time, valve gear changes caused by indoor CO_2 sensor failure will also have a certain impact on the purification speed of PM2.5.

2) Valve failure: small return air valve blockage increases system energy consumption by 27.4% in summer; Small blockage of supply air valve, exhaust valve and return air valve reduce the regulation ability of indoor pollutants, reducing the purification capacity of PM2.5 by up to 43.5%. The reduction of CO_2 dilution capacity can make the system unable to complete the regulation of indoor CO_2.

3) Due to the deficiency of modeling with only a single pollutant as the target in the current research on indoor air quality assurance system, this paper builds a set of simulation model for the whole indoor air quality assurance system, including room, heat and cold source, fan, air duct, valve, sensor, pollution source and control means, to provide help for subsequent research.

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