Design of Control System for Fresh Air Conditioner

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Abstract. In response to the increasing requirements of most residents for indoor living conditions, the design of an air conditioner control system based on the STM32 single-chip microcomputer is proposed, and the touch screen is used as superior computer to monitor and adjust the temperature and humidity and air quality of each room. Complete the software and hardware design of the air conditioner control system and use the PID control algorithm to optimize the control process.

1. Introduction
In recent years, domestic green buildings have become increasingly popular. In order to ensure the sustainable development of the HVAC industry, while providing residents with good living conditions, reducing energy consumption as much as possible has become an important task and objective to be faced. Surveys show that people spend 89% of their time indoors[1]. The increase in the amount of fresh air is conducive to dilute and control of indoor pollutant concentrations and help reduce the impact of various indoor pollutants on human health and comfort. Wind energy consumption represents more than 30% of the energy consumption of air conditioner systems[2]. Increasing the amount of fresh air will also increase the energy consumption of the air conditioner. Rational use of fresh air can make VAV system energy saving at the same time, to ensure the air quality in the room, if the use of fresh air is not reasonable, on the one hand, it will increase the energy consumption of the air conditioner system with VAV, on the other hand, this can lead to fresh air volume insufficient in certain areas of the air conditioner system, indoor air quality deteriorates [3].

Wang et al. proposed a continuous segmented control strategy based on the control of ventilation on demand. Studies show that using this control strategy can reduce the energy consumption of indoor air conditioner and improve the quality of indoor air [4]. In [5], based on DDC design, the primary air return scheme of central air conditioner in intelligent building has many advantages, such as convenient temperature and humidity regulation, safe and stable system operation, etc.

Full use of computer technology in the air conditioner system can effectively improve the performance of fresh air conditioner, reduce operating costs, improve indoor air quality, temperature and humidity, and facilitate management centralized. This paper will introduce the design of the fresh air conditioner control system.

2. Control Requirements for Fresh Air Conditioner
The control requirements of the fresh air conditioner is mainly the control of the temperature and humidity in the room and the air quality, so that the indoor temperature and humidity are stable at a level that meets residents' requirements, and indoor air quality is maintained within a range beneficial to human health. The structural diagram of the fresh ventilation unit is shown in Figure 1.
3. Controller Design

3.1. Mainboard Design
The system hardware circuit mainly comprises a main control circuit, a clock circuit, a data storage circuit, a switch input circuit, a switch output circuit, an analog output circuit, a RS485 communication and a CAN communication circuit. The material block diagram is shown in Figure 2.

(1) The main control circuit is mainly composed of a STM32 microcontroller. The single-chip microcomputer is connected to each module and the functions for collecting temperature and humidity in the room and controlling field devices are supplemented by software.

(2) The digital input circuit uses the isolation of the TIP521 optocoupler to detect the state of the external input.

(3) The switching output circuit is mainly composed of ULN2803 and 4094. It controls several relay outputs to ensure the stability of the control.

(4) The I / O port of the microcontroller is used to isolate the 4-20 mA current signal via the isolation of the optocoupler and the DAC chip. This current signal is used to control the inverter and therefore the fan speed.

Figure 1. Structure chart of fresh air unit.

Figure 2. Hardware schematic.
(5) The device's internal temperature and humidity sensor is attached to bus 485 and collects the temperature and humidity of the fresh air, the temperature and humidity of the supply air, the temperature and the humidity: return air, as well as the exhaust air temperature and downloads them to the touch screen. The touch screen is connected to the main control board via 485 to perform data interaction.

(6) The CAN bus is connected to sensors and dampers inside each room, and humidity in the room can be monitored and adjusted via the touch screen.

3.2. Software Design

The air handling unit is a typical high inertia system with pure hysteresis. It has a lot to do with the flow of interior personnel, interior objects and exterior weather conditions, so it is difficult to describe it with precise mathematical models[6]. The control flowchart is shown in Figure 3.

(1) When the indoor gas quality sensor detects that the concentration of CO2 and PM2.5 are higher than the value defined by the system, the ambient air valve is automatically adjusted to the expected position;

when the concentration of CO2 and PM2.5 is above a certain threshold, the ambient air valve Fully open, dilute the internal gas to reduce the concentration of CO2 and PM2.5.

(2) Supply air temperature control. The room sensor collects the indoor temperature and sends it to the microcontroller via the serial port. The user-defined temperature is compared to the collected temperature. The PID control algorithm is used to adjust the opening of the cold / hot water valve to keep the indoor temperature consistent with the temperature set by the user.

(3) Supply air humidity control. The room sensor collects indoor humidity and sends it to the single-chip computer via the serial port. The user-defined humidity is compared to the collected humidity. The PID control algorithm is used to adjust the humidifier's electrical control valve to keep the indoor temperature consistent with the user-defined temperature.

(4) Alarm control. When the fresh air valve and the fan fail, the contactor is closed and the controller sends an alarm signal to the touch screen based on the contactor dry node.

![Figure 3. Control flow chart.](image)

4. Model Establishment

The model of fresh air conditioner-system is first established. Some assumptions are made as follows:

**Assumption 1**: The heating process is with equal humidity.

**Assumption 2**: The transfer function between the cold water valve and the output temperature of the surface cooler is one first-order inertia link.
4.1. Room Temperature Model[7]
The room temperature model is as follows.

\[
CV \frac{dt}{d\tau} = (G_o \rho_o C_{p,a} + q_a) - \left( G_o \rho_o C_{p,a} + \frac{t_a - t_o}{R} \right)
\]

\( C_v \) is the specific heat capacity of room air, \( V \) is the volume of the room, \( t_a \) is the room air temperature, \( \tau \) is time, \( G_o \) is the amount of air entering the room, \( \rho_o \) is the air density, \( C_{p,a} \) is the specific heat capacity of air at constant pressure, \( t_o \) is the temperature of the supply air, \( q_a \) is the heat dissipation of the indoor heat source, \( t_o \) is the temperature of the room air, \( t_o \) is the outdoor temperature, \( R \) is thermal resistance of the room.

The relationship between indoor temperature \( I_n(s) \) and supply air temperature \( I_s(s) \) is as follows.

\[
\frac{t_o(s)}{t_a(s)} = \frac{K_c}{T_c + 1}
\]

\( K_c = \frac{G_o \rho_o C_{p,a}}{G_o \rho_o C_{p,a} + \frac{1}{R}} \) is the room temperature gain, \( T_c = \frac{CV}{G_o \rho_o C_{p,a} + R} \) is the room temperature constant.

4.2. Room Humidity Model
The room humidity model is as follows.

\[
\rho_o V \frac{d(d_s)}{d\tau} = G_o \rho_o d_s + D_f - G_o \rho_o d_o
\]

In the formula, \( d_s \) is the air moisture content indoor, \( d_s \) is the moisture content of the supply air, \( D_f \) is the heat dissipation of room equipment and people.

The relationship between the final air moisture content \( d_s \) and the indoor moisture content \( d_o \) is as follows

\[
\frac{d_s(s)}{d_o(s)} = \frac{1}{T_h + 1}
\]

where \( T_h = \frac{V}{G_o} \) is the time constant of the room humidity object.

4.3. Heating Process Model
The heating process model is as follows.

\[
\frac{m_a C_h}{\alpha A_h} \frac{d(t_{a, \text{out}})}{d\tau} + t_{a, \text{out}} = \frac{G_{a, \text{v}}}{G_o} t_a + \frac{G_{a} - G_{a, \text{v}}}{G_o} t_{a, \text{r}} - \frac{r_v}{G_o \rho_o C_{p,a}} W
\]

Where \( m_h \) is the mass flow of the heater, \( C_h \) is the specific heat capacity of the heater, \( t_{a, \text{out}} \) is the air temperature of the heater, \( \alpha_A \) is the cross-wind heat transfer coefficient of the heate, \( A_h \) is the heat exchange area of the heater side wind \( G_{a, \text{v}} \) is the fresh air, \( t_{a, \text{r}} \) is the return air temperature, \( r_v \) is the latent heat of vaporization of the heated steam, \( W \) is the mass flow of the heater.

The transfer function between \( W \) and \( t_{a, \text{out}} \) can be obtained as follows

\[
\frac{t_{a, \text{out}}(s)}{W(s)} = \frac{K_{t_h}}{T_{t_h} + 1}
\]
where $K_c = \frac{r_v}{G_a \rho_a C_{p,a}}$ is the heater temperature target gain, $T_{1h} = \frac{m_i C_h}{\alpha_w A_a}$ is the heater temperature target time constant.

4.4. Condenser Model
According to the Assumption 2 made in the previous modeling, we will approximate the transfer function between the cold water valve and the temperature sent by the condenser as a first-order inertia link.

$$\frac{K_{vc1}}{T_{vc1} + 1}$$

Similarly, the transfer function between the cold water valve and the humidity of the condenser supply air can also be expressed as a first-order inertia link.

$$\frac{K_{vc2}}{T_{vc2} + 1}$$

4.5. Temperature and Humidity Control System
Based on Assumption 1, the diagram of the temperature and humidity control system is shown in the figure 4.

**Figure 4.** Control flow chart.

Where $G_{11}(s)$ is the transfer function between steam flow $u_1$ and indoor temperature $s_t$, $G_{12}(s)$ is the transfer function between cold water regulating valve $u_2$ and indoor temperature $s_t$, $G_{21}(s)$ is the transfer function between cold water regulating valve $u_2$ and indoor humidity $d_i$.

5. Matlab Simulation Experiment
Through continuous experiments, a set of PID parameters is obtained. Control system diagram are built using the Simulink module in Matlab, as shown in Figure 5:

**Figure 5.** Simulation diagram
The temperature response curve is shown in Figure 6:
It can be seen from the figure that the temperature can reach the set value after several fluctuations.

The humidity response curve is shown in Figure 7:
It can be seen from the figure, the humidity will soon reach the set value.

6. Conclusion
This design uses the STM32 single chip microcomputer as the main chip, uses the DDC with touch screen as the superior computer and combines the PID control algorithm to adjust the indoor air quality as well as the temperature and humidity to meet the residents' requirements, which not only ensures good control, but also improves energy-saving effects.

7. References
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