Energy Consumption Optimization and Emission Reduction of Subway Station Air Conditioning Systems

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Abstract: The air conditioning system of subway station is an important energy consumption unit in operation, and the energy consumption accounts for more than 45 % of the total energy consumption of the station. Existing systems generally have problems such as high energy consumption and inflexible regulation in design and operation : energy consumption is significantly affected by passenger flow and environment, but the traditional model lacks dynamic adjustment, resulting in waste ; the design of some equipment and control schemes is unreasonable, such as the inefficient operation of fans and pumps, which further increases energy consumption. In view of the above situation, this paper proposes an optimization strategy for ' design-operation-control ' : in the design stage, the energy saving potential is improved through system layout optimization and large temperature difference air supply ; in the operation stage, combined with load forecasting, variable frequency speed regulation and automatic control optimization, a coordinated control adapted to passenger flow and environmental changes is constructed, taking into account comfort and energy consumption constraints, to achieve stable and reliable energy saving.

Keywords: Energy consumption optimization; Emission reduction; Subway air conditioning; Energy saving technology; Dynamic control

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1. Introduction

The air conditioning system of subway station is responsible for temperature and humidity regulation, air quality improvement and equipment heat dissipation, which directly affects passenger experience and operation safety. Its high energy consumption characteristics are prominent. The energy consumption of ventilation and air conditioning accounts for more than 45 % of the total energy consumption of the station. Reducing energy consumption on the premise of ensuring functionality has become a key issue in the green operation of subways.

The current problems focus on low operating efficiency, insufficient design optimization and limited dynamic regulation. Air conditioning energy consumption is significantly affected by passenger flow and environment, but the traditional mode lacks targeted adjustment, resulting in waste. Some stations still have room for optimization in the selection of cold source schemes and water system control strategies. During the peak and transfer periods, the load and fresh air demand fluctuate rapidly. If the fixed setting and operation curve is used, the fan, pump and chiller will deviate from the high efficiency area for a long time. Therefore, it is necessary to construct a collaborative optimization framework that fits the working conditions, and to carry out the whole process review of design, operation and control.

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About the Author

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2. The Energy Consumption Status of Air Conditioning System in Subway Station

(1) Analysis of the main sources of energy consumption of air conditioning system

The energy consumption of air conditioning in subway station mainly comes from ventilation, refrigeration and water circulation. The energy consumption of ventilation and air conditioning accounts for more than 45 % of the total energy consumption of the station. Its composition covers equipment such as fans, pumps and chillers. The wind end involves the coupling of fresh air, return air and supply air ; the water end contains two-stage transportation and heat transfer of chilled water and cooling water ; the cooling source needs to balance the cooling capacity and energy efficiency under different outdoor conditions. The dynamic change of passenger flow has a significant impact on transient energy consumption, and the operation strategy should rely on real-time load forecasting and time-sharing regulation. If a clear response relationship is established between ventilation rate, air supply temperature difference and chilled water temperature, invalid operation and redundancy can be reduced under the premise of satisfying air quality and heat and humidity boundary.

(2) Summarize the existing research on energy consumption evaluation methods.

The evaluation methods mainly focus on load forecasting, system modeling and optimal control. The transient energy consumption prediction model evaluates hourly energy consumption and supports the optimization of cold source scheme through time-sharing regulation and load judgment . It takes the coupling of time-varying load and equipment efficiency curve as the core, and combines multi-period boundary conditions to output the matching relationship between power consumption, cooling capacity and air volume. In the verification stage, the measured data is used to identify the parameters to improve the extrapolation reliability. The optimization model based on numerical simulation adopts distributed parameter method and sequential module method, and carries out automatic control adjustment in combination with actual working conditions. The energy consumption is reduced by 8.7 % -23.6 % , and the heat transfer and fluid characteristics are described in a modular manner, which is convenient for linkage simulation with control strategies to quantify the energy-saving effects of different setting strategies.

3. Analysis of Energy Consumption of Air Conditioning System in Subway Station

(1) Explore the main factors affecting energy consumption

Energy consumption is affected by design layout, operation mode, passenger flow change and environmental parameters. The energy consumption of ventilation and air conditioning accounts for more than 45 % of the total energy consumption of the station. Optimization design and operation are the key to energy saving. The dynamic energy saving of 27 % ~ 78 % can be obtained by using large temperature difference air supply and frequency conversion of fan and pump. In terms of spatial layout, the air distribution of the station hall and the platform, the location of the equipment room and the length of the pipeline change the pressure drop and heat transfer, and determine the benchmark energy consumption. In terms of operation strategy, supply air temperature and humidity setting, minimum fresh air ratio control and transition season mode switching jointly shape the energy consumption-comfort balance. The contribution of peak passenger flow and arrival-departure frequency to sensible heat and latent heat load is nonlinear. If the response is delayed or the feedback quality is insufficient, the deviation of power consumption will expand.

(2) Analysis of the shortcomings of the existing system design

The existing design restricts the energy saving effect in many aspects. The system design stage does not fully consider the dynamic load, and it is difficult to adapt to the changes of passenger flow and environment during operation, resulting in waste . Capacity configuration is often guided by safety margin and lacks an elastic scheme

that matches the load timing, forming ' high distribution and low use '. At the same time, the common scheme adopts the fixed operation mode, and the chiller, water pump and fan lack dynamic optimal control, and the efficiency is low . The sensor arrangement and the quality of the measuring point are insufficient, and it is difficult to support the reset of the set value. Unbalanced hydraulic and air duct, unreasonable distribution of local resistance and end, and energy consumption of lifting transportation and distribution. The disconnection between design and operation and maintenance, and the lack of coordination between equipment and control have become the root causes of long-term high energy consumption.

4. Energy Consumption Optimization Strategy and Technology

Introduction of energy-saving technology and control strategy

Energy saving can be achieved through a variety of technologies and control strategies. Based on the optimization of the improved tuna fish swarm algorithm, by dynamically adjusting the water supply temperature of the chiller and the frequency of the chilled water pump, the global optimization is realized under the change of load and environment, and the energy saving rate is up to 55 %. This method combines group search and local optimization to construct a model with minimum energy consumption as the goal and comfort and air quality as constraints, and improves convergence with boundary penalty and weight update. The energy consumption optimization model is established by numerical simulation technology. Through parameter analysis and automatic control optimization, dynamic adjustment is realized under different working conditions, and energy consumption is reduced by 8.7 % -23.6 %. At the application level, combined with variable frequency drive and set value reset (supply air temperature, chilled water supply and return water temperature difference and minimum air volume constraint), the linkage control of the air-water system is implemented to make the equipment in the high-efficiency area, and a smooth transition during the season change and day and night switching.

5. Future Development Trend and Prospect

(1) Analyze the application prospect of new technologies in energy consumption optimization

The application prospect of new technology in energy consumption optimization is clear. The research based on numerical simulation shows that the model established by distributed parameter method and sequential module method can realize automatic control optimization under different working conditions, and the energy consumption is reduced by 8.7 % -23.6 % . The model describes the nonlinear response of the fan and the coil, and is coupled with the control strategy to provide a quantitative basis for the reset of the set value and the switching of the operating conditions. The transient energy consumption prediction model combined with load judgment and time-sharing regulation can guide the optimization of cold source scheme. The direct expansion evaporative condensation scheme shows significant energy saving advantages , which provides decision support for scheme comparison and strategy formulation.

(2) Exploring the potential impact of intelligent control systems

Intelligent control has significant energy saving potential in subway air conditioning. Intelligent fuzzy control, improved algorithm optimization and wind-water linkage control have shown application prospects. The improved tuna fish swarm algorithm based on hybrid strategy can dynamically adjust the operation of water system with the change of load and environment, and the energy saving rate can reach up to 55 % . The project landing should achieve perception-decision-execution coordination : stable data acquisition and quality control to ensure that the state quantity is available ; the constraints and priorities are defined by an interpretable optimization model. It is deeply integrated with the field controller to ensure real-time update of the set value and smooth response of the

device. At the same time, it is necessary to pay attention to safety and reliability, establish an anomaly detection and fallback mechanism, and ensure that the basic services and energy consumption under emergency conditions are controllable.

6. Conclusion

This paper focuses on the energy consumption optimization and emission reduction of the air conditioning system in subway stations, and systematically analyzes the mechanism and application effects of various strategies. The improved tuna swarm algorithm, numerical simulation and automatic control design show that the optimized system can significantly reduce consumption under different working conditions, and the energy saving rate can reach up to 55 %, and can maintain efficient operation under dynamic load conditions. These results verify the feasibility and practicability of the strategy and provide technical support for energy conservation and emission reduction of subway stations.

There are still some directions worthy of further study. In the future, the intelligent prediction and control model can be constructed by combining real-time data to improve the response and energy saving effect. At the engineering level, the coordination of debugging and operation and maintenance should be improved, the cycle and process of data governance and model update should be clarified, and a closed loop should be formed in equipment maintenance, parameter review and strategy iteration to promote the stable replication of energy-saving measures in different stations. Through continuous model calibration and field verification, it is expected to achieve a higher level of energy consumption optimization and emission reduction benefits under the premise of ensuring comfort and safety.

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