Journal of World Architecture, 2023, Volume 7, Issue 1
http://ojs.bbwpublisher.com/index.php/JWA
ISSN Online: 2208-3499
ISSN Print: 2208-3480

Study on the Principle Model and Simplification of Subway Station Itemized Energy Consumption

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Abstract: Owing to the constant modernization and urbanization of China, most cities have subways, and the total power consumption of subway stations has been rising, which contradicts with China's green goals. In this regard, energy consumption indicators for major energy use projects in subway stations should be established, comprehensive evaluation and detailed research on the current situation of subway operation should be conducted, and specific energy-saving measures should be taken from a diversified perspective. It is crucial to systematically sort out the principle of sub-item energy consumption in subway stations, and practice and explore the specific simplification measures of the principle model of sub-item energy consumption, so as to lay a solid foundation for achieving the goal of reducing energy consumption of subway stations.

Keywords: Subway station; Itemized energy consumption; Principle model; Simplified approach

Online publication: February 13, 2023

1. Introduction

Based on the actual operation characteristics of the main energy consumption systems in subway stations, this paper establishes a set of useful and detailed sub-item energy consumption principle models, including air conditioning, lighting, and vertical transportation system. By inputting the station operation and building name into the system, the rationality of the actual energy consumption of each sub-item of the system can be accurately calculated. Considering the large workload of data collection, the important parameters in the energy consumption model are extracted and integrated through sensitivity analysis, so that the model is effectively simplified, which help ensure that the actual engineering needs are fully met. The accuracy of the root mean square error variation coefficient of the corresponding energy consumption model of the simplified ventilation system, air conditioning system and vertical transportation system meets the standard requirements, which means it can not only greatly reduce the difficulty of data collection, but is also versatile. Besides, this model can also quickly and accurately evaluate the actual operation of the subway station and its energy-saving potential.

2. Principle model of subway station itemized energy consumption

2.1. Energy consumption principle model of ventilation and air conditioning system in subway station

The power consumption of ventilation and air conditioning system accounts for a large proportion of the total subway energy consumption. The corresponding energy consumption principle model is mainly composed of system energy efficiency model and cooling load model. The characteristic model of subway station mainly includes ventilation and air conditioning system, energy consumption and cooling load, system energy efficiency ratio, operation time of ventilation and air conditioning system and other factors.

2.1.1. Cooling load model

As the subway station is usually underground, the solar radiation is negligible, and the soil temperature is relatively stable, which can keep the heat of the outer enclosure structure in a stable state all the time. The station cooling load is slightly affected by the heat storage factor of the maintenance structure, so the cooling load can be directly regarded as the heat gain. Generally, the cooling load of the ventilation and air conditioning system in subway stations mainly involves the following aspects:

(1) Personnel load

Personnel load mainly includes factors as personnel, total heat dissipation, number of people entering the station, number of people leaving the station, passengers' stay time in the hall when entering and exiting the station, and many more.

(2) Mechanical fresh air load

In the natural ventilation season, the metro station is cooled by mechanical fresh air. In the air conditioning season, the parameters of mechanical fresh air need to be considered, mainly including air density, air volume, outdoor and station air specific enthalpy difference and other elements.

(3) Fan temperature rise load.

The main influencing elements are few, that is, the actual operating power of the forced draft fan.

(4) Unorganized infiltration load

It mainly includes the unorganized air seepage volume entering the waiting hall from the entrance and exit of the subway station and entering the platform through the screen door, the specific enthalpy difference between the outdoor air and the platform air of the subway station, the specific enthalpy difference between the subway tunnel and the platform air, and other factors.

(5) Heat insulation of enclosure structure

It mainly includes heat transfer coefficient and heat transfer of safety door, subway tunnel temperature and platform temperature. In the process of calculating the heat transfer of the maintenance structure outside the station hall layer and the platform layer respectively, the platform layer is usually about 15 meters underground. The surrounding soil temperature can be considered constant and a steady-state calculation method can be adopted. The factors that affect the heat gain of the peripheral structure mainly include the area of the side wall and roof of the station hall layer, the burial depth, the monthly average temperature of the ground surface, the air temperature of the station hall, the distance between the concrete roof of the station hall and the ground surface, the heat transfer of the peripheral protective structure of the platform layer, the heat transfer coefficient of the wall surface, the thickness of the concrete, the soil thickness, the concrete thermal conductivity, the soil thermal conductivity, the area of the outer protective structure of the platform layer, soil temperature of constant temperature layer, and many more.

(6) The heat dissipation capacity of equipment in the station

The heat dissipation capacity of equipment in the station mainly includes vertical transportation system equipment, lighting equipment, display screen, ticket vending machine, ticket gate, and other factors. The cooling load generated by lighting equipment in the heat dissipation process is usually calculated according to its power. The heat dissipation capacity of vertical transportation system equipment is usually calculated based on the energy consumption model of vertical transportation system. The cooling load generated by the operation of other equipment is approximately calculated according to the corresponding power.

2.1.2. System energy efficiency model

In the air conditioning season, the energy efficiency of the ventilation and air conditioning system in the subway station mainly includes the efficiency of the heat sink and the air conditioning terminal, the distribution coefficient of cold water and cooling water, and the performance parameters of the chiller. In the natural ventilation season, the energy efficiency of the ventilation and air conditioning system in the subway station can be regarded as the energy efficiency ratio of the air conditioning terminal.

2.2. Energy consumption principle model of subway station lighting system

As natural light cannot be used for the lighting of underground space of subway station, the influence of lighting can be ignored in the process of calculating lighting coefficient, and the operation mode and operation power is stable. The influencing factors mainly include lighting power, lighting area, lighting system, and service time.

As the location of the subway station hall floor is usually 5-10 meters deep underground, there is little temperature fluctuation, which does not significantly affect the formation temperature. Therefore, the monthly average soil temperature can be used to calculate the energy consumption of the basement lighting system. The relevant factors include the area of the side wall and roof of the station hall, the buried depth of the underground, the monthly average surface temperature, the air temperature of the station hall, and the distance between the concrete roof of the station hall and the ground [1].

2.3. Energy consumption principle model of vertical transportation system in subway station

The influencing factors of energy consumption of vertical transportation system in metro stations mainly include vertical transportation system, actual operation power, and operation time of equipment. Generally, the subway vertical transportation system is divided into escalator and vertical elevator. Due to the obvious differences between the two in terms of working mode and energy consumption characteristics, it is necessary to establish models for calculation according to the actual situation [2].

2.3.1. Vertical elevator model

The vertical elevator under normal working condition is mainly divided into use mode and standby mode. In the use mode, the power consumption of a vertical elevator is high but the time of consumption is short. The specific working time is mainly affected by the number of train arrivals and the number of passengers. The relevant influencing factors include the number of times the vertical elevator runs after a single train arrives at the station, the number of train arrivals, the lifting height of the vertical elevator, and the rated running speed of the vertical elevator. In standby mode, the power consumption is low and the time of consumption is long. The specific waiting time is the total working time minus the working time in use mode [3].

2.3.2. Escalator mode

Generally, the escalator is mainly monitored by induction frequency conversion, there are sensors on the escalator that monitors whether there are passengers entering the escalator, and switches the signal mode based on the monitoring results. The working mode of escalator operated by induction frequency conversion control mode mainly includes rated speed no-load mode, low speed control mode and rated speed loaded mode, which are divided into two states: up escalator and down escalator.

As for the up escalator, during peak hours, a crowd passengers get out of the train and then take the escalator to leave the station. When passengers take the escalator, the operation mode of the escalator is mainly at rated speed with load. After the passengers have left the escalator for some time, the running mode of the up escalator becomes low-speed no-load. In this process, the specific running time of the rated speed loaded mode of the up escalator mainly depends on the number of single underground arrivals and the density of single passenger alighting. The specific running time of rated speed loaded mode mainly depends on the switching time of the mode. The actual operation time of low-speed no-load mode mainly depends on the time interval of subway arrival [4].

For the down escalator, the energy consumption calculation method is highly similar to that of the up escalator, and the specific difference is mainly the number of switching operation modes. The entry status of subway station passengers is relatively scattered. Suppose that when passengers enter the station in batches, the down escalator will transport the next batch of passengers after transporting one batch of passengers. However, when the time interval between escalator operation mode switching is significantly lesser than that between two batches of passengers, after the first batch of passengers are transported, the escalator operation status will automatically switch to low-speed no-load mode, otherwise it will not switch. According to the calculation of the total number of people entering the station in a fixed period and the number of people entering the station continuously, the number of passenger batches transported by the down escalator can be obtained [5].

3. Simplified version of principle model of sub item energy consumption in metro station

3.1. Sensitivity analysis

Through the detailed analysis of the principle model of sub-item energy consumption in metro stations, the energy consumption calculation method of main systems can be determined in combination with the actual operation of metro stations, which can not only effectively evaluate the energy-saving operation status of each system, but also tap its energy-saving potential. However, in the relevant models, the way to input parameters is highly complex, which will lead to an increase in the workload of field research and data collection and cannot be effectively implemented in actual work. Therefore, the actual energy consumption principle of the ventilation system, lighting system and vertical transportation system of the subway station should be determined to simplify the model, so as to ensure that the relevant model can be applied to any subway station on a large scale, and so that the energy-saving operation evaluation and energy-saving goals can be effectively achieved [6].

Sensitivity analysis is mainly carried out by using a quantitative method to deal with the impact of input on the output, accurately identify the influential parameters, and effectively simplify the energy consumption model by defining the input parameters that can be fixed in any value range within a specific distribution area without affecting the final results. The sensitivity analysis is used to process the energy consumption models of the air conditioning and ventilation system, lighting system, and vertical transportation system of the subway station, which sorts out relevant parameters, ensure that only a few parameters are input into the system, and many sensitivity indicators can be obtained, and most of the input parameters will not affect the accuracy of the model output results [7].

3.2. Research on model simplification

In the process of sensitivity treatment of the simplified energy consumption model of the ventilation and air-conditioning system, there are many input parameters, mainly including environmental parameters in the station, passenger flow, equipment parameters, building information, and many more. In all parameters, when a small number of detailed investigation parameters are input for sensitivity test, other parameters adopt the social average value, and the mean square of the simplified model is used as the standard. After reasonably increasing the detailed investigation parameters for sensitivity testing, the investigation parameters adopting social average values will be reduced, and the root mean square value of the simplified model will not change much compared with the standard [8].

For example, there is a large temperature difference between winter and summer in some places. In the process of sub-item energy consumption test for a 2-floor standard island subway station, the principle model and simplified model are respectively used to simulate the energy consumption of the air conditioning and ventilation system of the subway station. Through the analysis of the final results, it can be seen that the error between the principle model and the simplified model is small, and it is always within the acceptable range of the engineering precision application field. The test results of this method in the energy consumption principle model of the subway lighting system and the vertical traffic energy consumption principle model are highly similar, so it is determined that the simplified model can evaluate and tap the actual operation of the subway station and the energy-saving potential [9].

4. Conclusion

In order to conduct a detailed study on the reasonable energy consumption indicators of subway stations, it is necessary to design a sub-item energy consumption model of subway stations in advance. This model is based on statistical regression and operation principles, which can not only quickly assess the energy consumption of each sub-item of subway stations, but also provide a strong reference for professionals to fully understand the current building energy consumption. Among them, the application feasibility of the principle model is obviously higher than that of the regression model, mainly because the main aspects involved in the principle model are building structure, ventilation, personnel, operation, etc. Through simulating the real situation of the building model, and combined with the detailed analysis of train sets, passenger flow, buildings and other information, the most reasonable energy consumption indicators of the subway station can be summarized. The factors that the actual energy consumption of the subway station exceeds or falls below the indicators are analyzed, so as to provide strong guidance for the realization of normal operation and energy-saving transformation goals.

Disclosure statement

The authors declare no conflict of interest.

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