Study on the Influencing Factors of Energy Consumption of the Shopping Mall in Kunming

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Abstract

The Energy consumption of the shopping mall is regular, and it is easy to make statistics and simulation analysis. In this paper, orthogonal test method was used to study the influencing factors of energy consumption of a shopping mall in Kunming, and it was found that the influence of the internal factors of the building was greater than that of the building itself through the analysis of the range of factors; it is concluded that the lighting power density, lighting time, air conditioning temperature and ventilation times have a significant impact on the building energy consumption of the shopping mall through significant analysis; and obtaining the energy-saving analysis according to the experimental results finally.

Keywords

Energy consumption, orthogonal test, Shopping Mall.

1. Introduction

Shopping mall is related with the people's daily activities so closely, and its function use of every region is clear, a fixed business hour, the time of equipment running is stable, strong regularity of building energy consumption, all of these is conducive to make energy statistics and simulation results. Many scholars used different methods to study shopping mall energy consumption. A. Marta [1] studied the use of reasonable ventilation and cooling strategies in shopping mall to reduce energy consumption; F. Zhang [2] put forward and analyzed several hot summer and winter warm area shopping malls and pointed out that energy-saving methods can be considered. J.X. Qu [3] conducted a sample survey on the energy consumption of shopping mall in several cities in Shandong Province to analyze the heating energy consumption, overall energy consumption and energy composition of shopping mall. J.X. Wu [4] conducted statistical analysis on the measured data of lighting energy consumption in 32 shopping malls in China and discussed the factors that affected the lighting energy consumption of shopping mall. Some scholars have used orthogonal test to study the energy consumption of buildings. K.Y. Tang [5] obtained the significant order of influencing factors of energy consumption of residential buildings in Beijing by using orthogonal test and conducted energy saving analysis. J. Wei[6] studied the influences of the building energy consumption caused by building envelope construction by using orthogonal test. J.P. Chu [7] proposed that the orthogonal test, range analysis and significance analysis could be used to study the kinds of factors that affect the level of energy consumption of building air conditioning. The above research showed that the commonly used factors are exterior wall, exterior window, roof, shading coefficient, window-wall ratio, lighting index, interior design temperature, ventilation times and so on.

In the view of the studies of energy consumption of shopping mall are mostly located in hot summer and cold in winter, hot in summer and warm in winter, cold areas, and it is lack of the research for

temperate areas. However, with the social accelerating and economic development of urbanization, Kunming, as a representative city in temperate regions, has witnessed a rapid growth in the number and size of shopping malls. In this paper, taking a shopping mall in Kunming as an example to study the impact of energy consumption in shopping malls in temperate regions by the use of orthogonal test methods.

2. The background of a shopping mall in Kunming

2.1 The climate characteristic in Kunming

Kunming City is located in the central Yun-Gui Plateau, the north of the Dianchi Basin, the temperature difference per year is small, the daily is high [8], the annual average temperature is about 15℃, the hottest month is June, the average temperature is about 20℃, the maximum temperature is 28.8℃. The coldest month is December, the average temperature is about 8℃, the lowest temperature is -2℃. The annual average relative humidity is about 70%, the average relative humidity is the lowest in March and the highest is July. The annual total radiation is 5509MJ/m^2 [9].

2.2 The general situation of study profile

A shopping mall in Kunming is 6 floors, a total construction area of 109000 square meters, 6 floors is above ground, 3 is underground floors, the first floor is 5.7m high, the standard floor height is 5.1m. The project features are positioning the department stores, supermarkets, entertainment, office buildings, high-end theater as a whole, as well as the region of the corresponding service catering, services, fitness and other facilities. Fig. 1 is a shopping mall 3D model diagram. The shopping mall has a big space scale, huge population density, business hours is 12 hours per day, and the holidays is without a break throughout the year. The energy consumption of the shopping mall can be divided into energy consumption of air-conditioners, energy consumption of lighting, energy consumption of elevators, energy consumption of water supply and drainage facilities, etc. The energy consumption monitoring system of its configuration shows that the actual energy consumption of shopping malls was 609.86MWh/ a in 2016, the center's air-conditioning system and lighting energy system is larger, accounting for 43%, and 30% of the total energy consumption, of which air-conditioning system consumption is 262.2MWh/ a, lighting system energy consumption is 182.02MWh/ a.

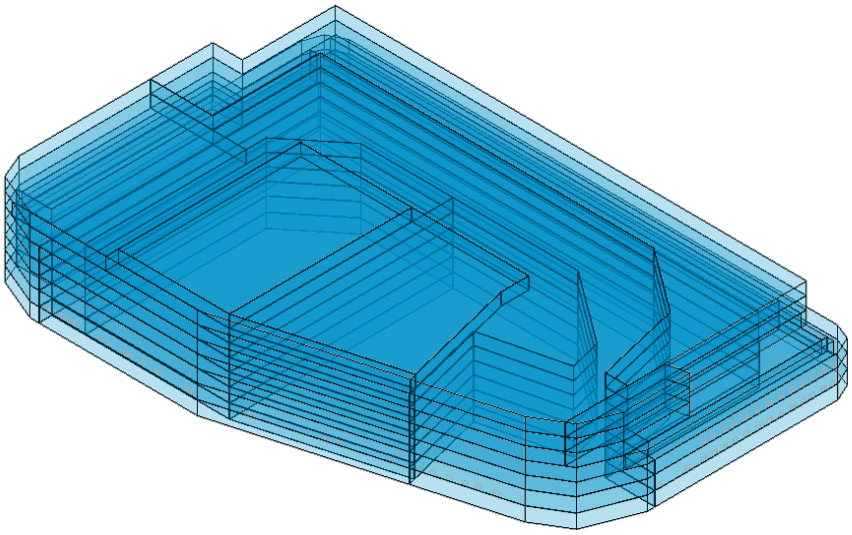

Fig. 1 3D model of the shopping mall

3. Analysis on the Affecting Factors of the Energy Consumption of Shopping Malls

Various types of energy consumption in shopping malls are affected by many factors. According to the ways of the influencing factors on the energy consumption of buildings, the influencing factors of building energy consumption are mainly divided into three aspects: building ontology, internal factors, external factors. The building ontology includes the external walls, windows, roof, floor, window wall ratio, shading coefficient, etc. ; internal factors including the per capita use of area, indoor personnel density, the using time caused by the person, the intensity of lighting , the power of the all kinds of electrical appliances , the constant temperature required in the room, the time of use of the air conditioner, etc. ; the temperature in outdoor, humidity, solar radiation intensity, wind speed and direction of the outdoor air, the position of the adjacent building, the vegetation around the building, etc.

Building ontology, internal factors and external factors have different effects on energy consumption in shopping mall. In order to quantitatively determine the impact of various factors on energy consumption, it is necessary to determine the main factors from a variety of factors and determine the impact of each major factor of energy consumption and explore the building energy conservation measures with the combination of the main factors. In the view of this, this paper used orthogonal test method to study the impact of various factors of energy consumption.

4. Research methods

4.1 Introduction of orthogonal test

Orthogonal test method is a method to be used to study multi-factor and multi-level [10], it has the advantages of less test times, lower test costs, shorter test cycles, simple calculation, flexible design and practicality Easy to grasp features. Compared with the general comprehensive experimental design method.

The basic principle is to design a test based on a standardized set of tables, and then using the mathematical statistics to analyze and process the data in the table1, which was selected from a comprehensive test which can be the representative points from all the tests, and then finding the optimal combination of factors through the experimental data, which can be used to form the best methods [11-13].

We need to determine whether to consider the interaction which exists between every factor when designing an orthogonal test header. The tests can be divided into two types, without considering the interaction and considering the interaction in accordance with the distinction between factors. The Orthogonal test that without considering interactions is not to consider the common impact between various factors, only to consider the impact of a single factor on the results. This method has the characteristic that the test results intuitive, and easy to conclude the characteristics of the analysis and also can meet the needs of the design, so this article uses this test method.

4.2 Design of orthogonal test

Energy simulation software Designbuilder4.6 has been used to simulate the shopping centers in different test conditions of building energy consumption through the establishment of different levels of representative tests, and calculating the energy consumption per unit area, and using the range method to analyze the test results intuitively and using the analysis of variance to verify the significance of the factors, then drawing conclusions. Selecting the factors of exterior wall type, roofing type, lighting power density, lighting time, air conditioning temperature and ventilation times are selected according to the representative choice of building ontology, internal factors and external factors, taking two levels for each one factor, and regardless of mutual interaction. The test using $L_8(2^7)$ orthogonal table, the impact of factors and the corresponding level of value in Table 1. In the external wall type, the heat transfer coefficient of Level 1 is 0.56W/(m^2·K), and the Level 2 heat transfer

coefficient is 0.88W/(m^2·K). In the roofing type, the heat transfer coefficient for level 1 is 0.6W/(m^2·K) and the level 2 heat transfer coefficient is 1.2W/(m^2·K).

Table 1 Influencing factors and the corresponding level value

Numble	factor	unit	Level 1	Level 2
A	Exterior type		200mm aerated concrete block + extruded board (XPS) within the insulation	200mm aerated concrete block
B	Roof type		150mm reinforced concrete + 50mm extruded polystyrene board insulation	150mm reinforced concrete + 20mm extruded polystyrene board insulation
C	Lighting power density	W/m	T5 lamp, power is 6W	T5 lamp, power is 10W
D	Lighting time	h	10	12
E	Air conditioning temperature	℃	26	25
F	Ventilation frequency	Times	2	4

4.3 Results and discussion

The results of orthogonal test are shown in Table 2. We can make an analysis of the range of influencing factors and the analysis of the significance of influencing factors through this table. The energy consumption per unit area of different test numbers in the table is calculated by Designbuilder simulation, k_i means the level of any one of the factors i, the arithmetic mean of the test results; R is the extreme value, R=max(k_i)-min(k_i) in either column.

Table 2 Results of orthogonal test

Test number	A	Empty column	B	C	D	E	F	Energy consumption per unit area(kWh/m^2)
1	1	1	1	1	1	1	1	29.08
2	1	1	1	2	2	2	2	42.45
3	1	2	2	1	1	2	2	36.02
4	1	2	2	2	2	1	1	36.96
5	2	1	2	1	2	1	2	34.03
6	2	1	2	2	1	2	1	37.8
7	2	2	1	1	2	2	1	35.63
8	2	2	1	2	1	1	2	34.4
k_1	36.12	35.84	35.39	33.69	34.32	33.61	34.86	
k_2	35.46	35.75	36.2	37.9	37.26	37.97	36.72	

4.3.1 Analysis of the impact of factors range

Ranking six factors on the impact of energy consumption in order according to the size of the extremum: Air Conditioning Temperature> Lighting Power Density> Lighting Time> Air Change Times> Roof Type> Exterior Type. The impact of internal factors within the building is greater than Building ontology, air conditioning and lighting system factors on the building energy consumption is greater than the impact of building envelope structure from these types of factors. The air-conditioning and lighting energy-saving measures should be the first consideration during the energy conservation in the shopping mall.

4.3.2 Impact factor analysis of significance

The range analysis method is simple and intuitive, the advantage is that only the results of a simple analysis of the test results can be drawn, but the disadvantage is that you do not know the analysis accuracy. In order to make up for the shortage, it is necessary to use variance analysis to calculate the square sum of the deviations from the degree of freedom and analyze the significance of the influence factors.

(1) Square of deviation

$$T = \sum_{i=1}^{8} y_i = 29.08 + 42.45 + \cdots + 34.4 = 286.37 \tag{1}$$

$$Q = \sum_{i=1}^{8} y_i^2 = 29.08^2 + 42.45^2 + \cdots + 34.4^2 = 10350.87 \tag{2}$$

Correction number:

$$C = \frac{T^2}{n} = \frac{286.37^2}{8} = 10250.97 \tag{3}$$

Total sum of squares:

$$SS_T = SS_1 + SS_2 + SS_3 + SS_4 + SS_5 + SS_6 + SS_e \tag{4}$$

$$SS_T = Q - C = 99.9 \tag{5}$$

A factor sum of squares:

$$SS_1 = \frac{1}{8}(K_1 - K_2)^2 = 0.878 \tag{6}$$

In the same manner, SS_2, SS_3, SS_4, SS_5, SS_6, and the square of the sum of the squared deviations SS_e.

(2) The degree of freedom of influencing factors

Total degrees of freedom:

$$df_T = n - 1 = 7 \tag{7}$$

A to F Factor degrees of freedom:

$$df_1 = df_2 = df_3 = df_4 = df_5 = df_6 = r - 1 = 1 \tag{8}$$

Error degree of freedom:

$$df_e = r - 1 = 1 \tag{9}$$

(3) The mean square of influence factors

A factor mean square value:

$$MS_1 = \frac{SS_1}{df_1} = \frac{0.878}{1} = 0.878 \tag{10}$$

Similarly, we can find MS_2, MS_3, MS_4, MS_5, MS_6, and the mean square error MS_e.

(4) F value of influencing factors

$$F_i = \frac{MS_i}{MS_e} \tag{11}$$

According to the above steps to calculate the results shown in Table 3.

Table 3 Test data analysis of variance

Factor	Square deviation of the sum	Degree of freedom	Mean square value	F value	Threshold (0.05)
A	0.88	1	0.88	23.1	F0.05(1,1) =161.45
B	1.16	1	1.16	30.6	
C	35.49	1	35.49	933.96	
D	17.32	1	17.32	455.7	
E	37.98	1	37.98	999.36	
F	7.04	1	7.04	181.59	
e	0.04	1	0.04		
T	99.9	7	99.9		

5. Conclusion

The results of the orthogonal test showed that the six factors influenced the energy consumption of a shopping mall in Kunming in the following order: Air-conditioning temperature> Lighting power density> Lighting time> Ventilation frequency> Roof type> Exterior type. When analyzing the significance of influencing factors, the lighting power density, lighting time, air conditioning temperature and ventilation times have a significant impact on the building energy consumption of the shopping mall. According to the above analysis shows:

(1) The internal factors of the shopping mall have greater influence than the building ontology, and the impact of air conditioning and lighting system on the building energy consumption is greater than the building envelope. The air-conditioning and lighting energy-saving measures should be considered first in energy-saving retrofit.

(2) Air conditioning energy consumption can be greatly reduced by setting a reasonable air-conditioning temperature to reduce the heat transfer temperature difference between indoor and outdoor.

(3) Through the selection of energy-saving lamps, lighting arrangements for a reasonable schedule to reduce lighting power density and reduce lighting time, can greatly reduce lighting energy consumption.

(4) Reducing the number of ventilation can be achieved to reduce fresh air load and reduce air conditioning energy consumption in the condition of meeting the minimum fresh air requirement.

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