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Analysis on Operation Characteristics of Air Conditioning System of Office Buildings

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Abstract

Building electricity consumption data can reflect building energy consumption level, evaluate effect on application of energy efficiency technology, enhance building energy efficiency management and promote energy efficiency retrofit in existing buildings. This paper showed annual, monthly electricity consumption level of 72 office buildings in Chongqing city. Then the paper figured out operation performance of air conditioning system at part load condition. 20 office buildings were further selected. The result found characteristics of hourly electricity load rate of air conditioning system during work time. At 8:00 and 18:00, electricity load rate of air conditioning was 27%-35%. In 9:00-11:00 period and 15:00-16:00, electricity load rate was 50%-70%. In 12:00-14:00 period, electricity load rate was 48%-63%. The paper also gave out frequency and probability of air conditioning system load rate in 0-25%,25%-50%,50-75% and 75%-100% four intervals. The general statistical analysis provided in this paper can analyze electricity characteristics of air conditioning systems in different districts, make unit capacity consistent with electricity load of air condition systems during design work, regulate electricity unit load depending on dynamic electricity load of air conditioning system in the process of air conditioning system operation. The method can supply effective guidance in improving measures of energy efficiency retrofit and making control regulation strategies in air conditioning system.

Keywords – *monitoring platform; statistical analysis; electricity consumption characteristics ; electricity load rate ; air conditioning system*

1. Introduction

In the past two decades, china has become the largest energy consumer and carbon dioxide emitter in the world [1]. From 1980 to 2012, the terminal energy consumption has increased by 5.8%, building energy consumption accounting for terminal energy consumption rose from 10% to 20% [1]. According to the trend, building energy consumption proportion will reach 23.1% [1]. China government promised that China's carbon emission would

not be increased in 2030. This meant building energy were responsible for energy consumption and carbon emission. However, there is current situation of high energy consumption and low energy efficiency in non-domestic buildings in China. At present air conditioning system retrofit is an important part in building energy saving work, and air conditioning energy use characteristics is also an important issue for analyzing building energy characteristic [2].

There has been much work of non-domestic buildings energy consumption analysis. At present electricity data analysis methods of air conditioning system are divided into simulation analysis and statistical analysis of investigation data. For simulation analysis method, it lacks of effective data supported during design work in new buildings or retrofit work in existing buildings [3]. And simulation results of air conditioning load distribution have some differences compared with real situation [4]. And for investigation method, it is difficult to achieve periodically test or long-term monitoring.

In recent years, due to the construction of energy consumption monitoring platform of non-domestic buildings, building electricity consumption real-time data can be collected.

In this research, statistical analysis on real-time electricity consumption of office buildings in Chongqing was carried out, obtaining the operation characteristics of air conditioning system of office buildings in Chongqing, to penetrate into learning the case of part load operation of air conditioning. It will contribute to chiller unit operating effectively at part load condition.

2. Method and Materials

2.1 Electricity load rate of air conditioning system

Building electricity load reflects electricity consumption level of all electrical equipment. Building electricity load value is not constant, and it changes over time. A fixed value like average electricity load cannot reflect actual operation status change of electrical equipment in a day, so this paper is based on hourly electricity load rate. Electricity load rate is defined as the ratio of real-time electricity consumption of all electrical equipment to designed capacity. According to ASHRAE handbook, the load rate of air condition system is defined as the ratio of real-time load to full load at the same operation condition.

To analyze the electricity consumption characteristics of air conditioning system of office building at different times, hourly air condition load rate of each building was calculated. Highest hourly electricity consumption of air condition system was regarded as installed capacity of chiller unit. The hourly air condition load rate was calculated as shown in (1).

$$P_i = Q_i / Q_m \quad (i=0,1,2,\dots,23) \quad (1)$$

P_i meant hourly load rate of air conditioning system. Q_i meant hourly load of air conditioning system. Q_m means the highest hour electricity consumption of air conditioning system in cooling period.

2.2 Electricity consumption data collected

Hourly electricity consumption data and basic information of 72 office buildings in the whole year 2014 were collected from Energy Consumption Monitoring Platform of Non-Domestic Buildings in Chongqing city. In office buildings, the normal operating schedule is a 11-hour working day from 8:00 a.m. to 6:00 p.m., five days a week. Therefore 3153600 hourly electricity consumption data could be obtained. The electricity consumption data were classified as four categories, and they were lighting and equipment system, air conditioning system, power system and special electricity use system. Lighting and equipment system includes lightings, office equipment like computers, printers, etc. Air conditioning system mainly includes chiller, terminal devices, water pumps and cooling tower. Power system includes power equipment such as elevator, fans and domestic water pumps. Special electricity use system includes electric equipment served for unconventional building functions like information center, gymnasium, large-scale medical equipment, etc.

3. Results and Discussion

3.1 Electricity characteristics of office buildings

Fig. 1 showed the current situation of annual electricity consumption per unit area of office buildings in Chongqing. The mean value of these was 57.97KWh/(m²·a), which was lower than 60KWh/(m²·a) [5] - the electricity intensity of office buildings in hot summer and cold winter zone. And large difference existed in different office buildings.

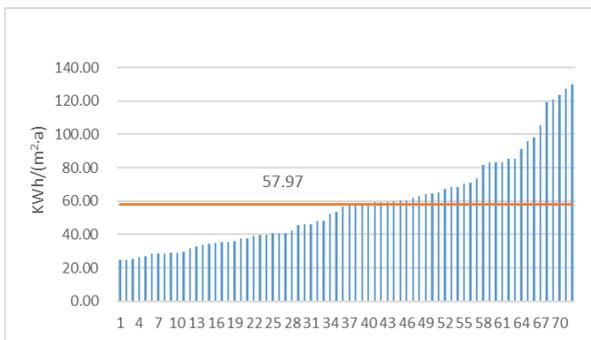


Fig. 1 Electricity consumption of office Buildings in Chongqing

According to Fig. 2, differences of electricity consumption in different electricity systems were shown. Bubble location represented electricity consumption mean value, bubble size represented fluctuation of annual electricity consumption per unit area. Since the circuits of lighting and equipment were difficult to be divided, and the main electricity equipment in office buildings were office equipment, its electricity consumption was the highest in all systems. And electricity consumption of power system in office buildings had the most obvious differences.

Fig.3 showed that monthly electricity consumption per unit area in the year 2014. Mean value, maximum, minimum and upper quartile were calculated. The figure indicated values of monthly electricity consumption per unit area changed with seasons. There were two peaks and two troughs. The electricity peaks time appeared in July, December and January, and troughs time appeared in April and October. Except air conditioning system, operation time of other electricity systems in office buildings in a whole year were relatively fixed. As for air conditioning system, it was greatly influenced by climate change because of refrigeration in summer and heating in winter. Therefore, the following analysis in this paper aimed at electricity load of air conditioning system in summer work time.

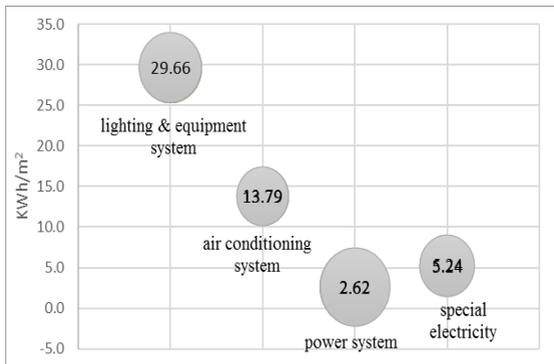


Fig.2 Distribution of annual electricity consumption per unit area of different systems

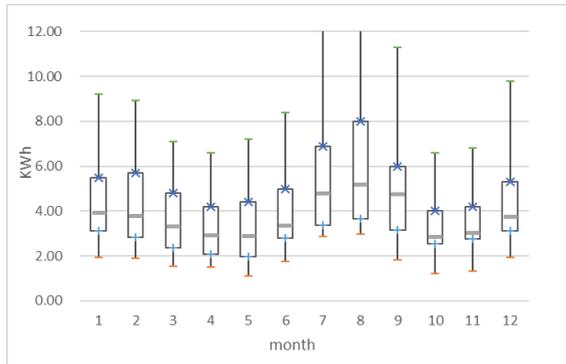


Fig.3 Monthly electricity consumption distribution of office buildings

3.2 Analysis of electricity load rate of air conditioning system

20 typical office buildings were further selected to analyze daily electricity load change of air conditioning system during work time in July 2014 shown in Fig. 4. The statistical results of total hourly electricity consumption were given out, presenting a structure of double peak. In order to learn the structure more clearly, polynomial fit was carried out. And the R^2 was 0.96. The first peak appeared at 10:00 and second peak appeared at 15:00. The first peak reflected that due to accumulated load during last night, the air conditioning system had to operate at nearly full load condition to reduce the temperature in buildings, even if outdoor temperature at that moment didn't reach the highest. The second peak showed that the electricity consumption was the highest due to the high outdoor air temperature and strong solar radiation.

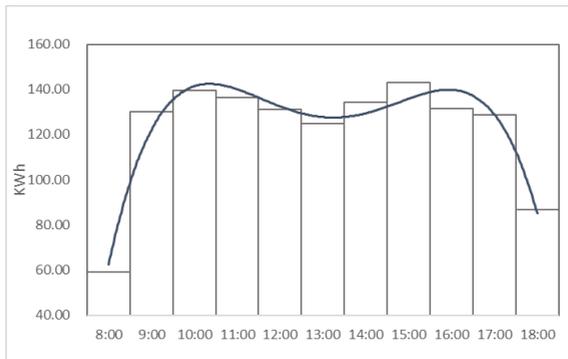


Fig. 4 Electricity load of air conditioning system of 20 office buildings

Mean value and standard deviation of air conditioning load rate at work time of 20 buildings were calculated, as shown in Fig 5 and Fig 6. During 9:00 to 17:00, the load rate of air condition ranged from 50% to 70%. The load rate was mainly influenced by outdoor temperature. During 8:00 to 9:00 and 17:00 to 18:00, the load rate increased and decreased rapidly, respectively, result from that people came to building between 8:00 to 9:00 and left between 17:00 and 18:00. In general, air condition system was closed about half to one hour before off time so that rest cooling load could be sufficiently used.

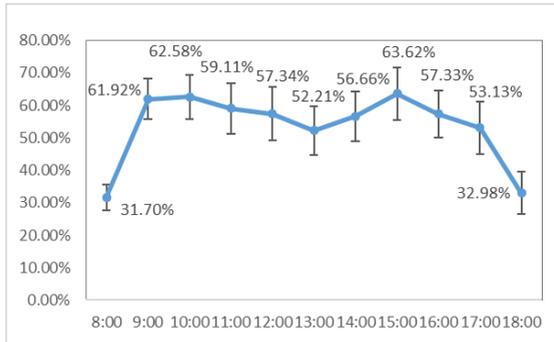


Fig. 5 Mean value and standard deviation of electricity load rate during work time

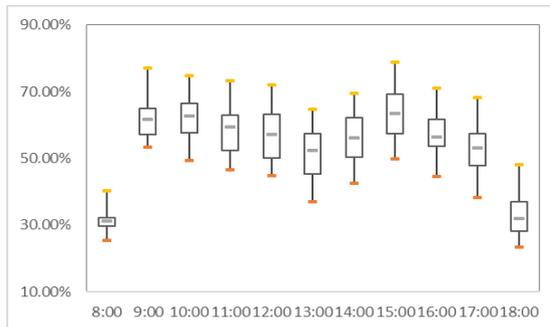


Fig. 6 Distribution of electricity load rate of air conditioning system

Building air conditioning electricity load was mainly influenced by heat transfer in envelope, solar radiation heat, human behavior and other factors. When doing unit design, its capacity always is depended on total load value, and their operation performance depends on dynamic load change. In order to learn the frequency of electricity load of office buildings in work time during July, regarding work period 8:00-18:00 as temporal scale, air conditioning load rate at each hour of 20 sample buildings as objects, 20 days as time period, 4,400 electricity load data could be acquired. upper quartile, median, lower quartile and maximum were carried out in

table 1. It showed that electricity load rate of air conditioning system presented the characteristic of 40%-60%-80%-100%. Air conditioning system often operated at part load condition, but seldom operated at very low load condition.

Table 1. statistical characteristic of air conditioning system

statistical characteristic	Air conditioning load rate
Lower quartile	41.40%
Median	58.57%
Upper quartile	80.55%
Maximum	100%

The capacity of chiller unit should be matched with air conditioning load. As for evaluation method of chiller unit performance of part load condition, at present, IPLV-Integrated Part Load Value are widely used. It represents the weighted average value of performance coefficient of single unit operating at 25%,50%,75% and 100% load rate. According to the load rate in IPLV evaluation method, four intervals were divided as 0%-25%, 25%-50%, 50%-75%, 75%-100%. Frequency and probability of air conditioning load rate appearing at each interval during work time in July were provided in Fig. 7. The frequency of interval 25%-50% was the highest, and except interval 0%-25%, the frequencies of other intervals were almost the same, and much higher than the frequency of 0%-25%. The result indicated that the performance coefficient of chiller unit operating at 25%-50%, 50%-75% load rate should be given more concern in order to ensure unit effective operation.

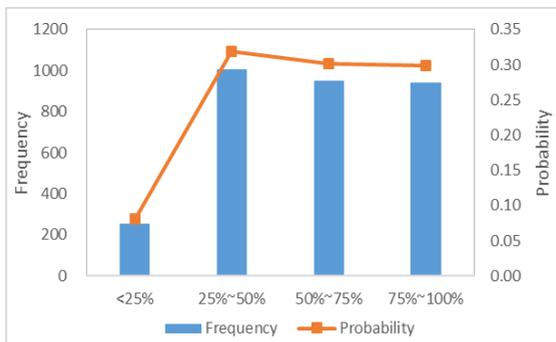


Fig. 7 Frequency and probability of load rate in four intervals

4. Conclusion

With the statistical analysis above, the electricity consumption and air conditioning electricity load data of office buildings in Chongqing, China can be generally obtained, as following:

The mean value of annual electricity consumption per unit area of office buildings in Chongqing city was 58KWh/(m²·a), which was slightly lower than standard value 60KWh/(m²·a) in hot summer and cold winter zone in china. The maximum and minimum electricity consumption per unit area in each building had large difference, so office buildings should be classified in detail in future work.

Annual electricity consumption per unit area of lighting and equipment system was the highest in all electricity system. It showed that with more lighting and office equipment increased, equipment electricity consumption couldn't be ignored. At present statistical electricity consumption data of air conditioning system weren't complete because of lacking gas consumption data in winter.

According to electricity load distribution of air conditioning system, the operation status of air conditioning system could be divided to three cases. Load rate of air conditioning was 27%-35% at early work time 8:00 and last work time 18:00. The load rate was 50%-70% during 9:00-11:00 and 15:00-16:00. The load rate was 48%-63% during 12:00-14:00. And electricity consumption load rate of each case can contribute to chiller unit capacity design work to make chiller unit capacity matched with air conditioning load.

The frequency and probability of air conditioning load rate of four intervals were shown in the figure 7. The frequencies of 25%-50%, 50%-75% and 75%-100% were similarly at 30%, and the lowest frequency appeared in 0-25%. The result could be reference to evaluate the chiller performance at part load situation.

Sample buildings in this paper were not cover all office buildings in Chongqing city because of some limitation. The characteristic analysis of electricity consumption in these buildings needs to be supplemented in the future.

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