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Procedia Engineering 121 (2015) 1856 – 1863

Procedia Engineering

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9th International Symposium on Heating, Ventilation and Air Conditioning (ISHVAC) and the 3rd International Conference on Building Energy and Environment (COBEE)

Operational electricity consumption analyze of VRF air conditioning sys-tem and centralized air conditioning system based on building energy monitoring and management system

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Abstract

This paper analysis the operational electricity consumption of 2 office buildings in campus with VRF and centralized air conditioning system respectively, according to the monitoring data derived from a building energy monitoring and management system. Results show that both two air conditioning systems have great potential for energy saving, and the adjustability of VRF air conditioning system is better than that of centralized air conditioning system. Finally, the main effective factors of energy saving in the operation process of two air conditioning systems are pointed out.

Peer-review under responsibility of the organizing committee of ISHVAC-COBEE 2015

Keywords: VRF air conditioning system; Centralized air conditioning system; Building energy monitoring and management system; Building energy analyze

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Peer-review under responsibility of the organizing committee of ISHVAC-COBEE 2015
doi:10.1016/j.proeng.2015.09.167

1. Introduction

The area of large public buildings is 5%~6% of the sum of town area, but the electricity consumption of this kind of buildings is 100~300 kWh/ (m^2•a), more than ten times of residential buildings [1]. Heating, ventilation and air conditioning system is responsible for approximately 50% consumption from total building energy consumption in developed countries [2]. Therefore, the electricity consumption in public buildings is a huge part of total energy consumption. Large public buildings generally adopt the centralized air conditioning system. VRF (Variable Refrigerant Flow) air conditioning system is causing more and more attention in recent years, due to its efficient operating and improving thermal comfort of indoor environment. VRF air conditioning system is a kind of variable refrigerant flow air conditioning system and its principle is Inverse Carnot Cycle as the same as other air conditioning system. The difference between VRF air conditioning system and centralized air conditioning system is whether heat exchange directly occurred between refrigerant and indoor environment. Scholars have done a lot of research on the efficiency [3], and energy saving potential [4] through numerical simulation and theoretical algorithm. Compared to the centralized air conditioning system, the adjustability and energy saving effect of VRF air conditioning system is worth studying. The present numerical simulation and theoretical analyze are not completely considered the impact of these factors, such as adjustability and energy saving potential, therefore, studying two systems characteristics of adjustability and energy saving potential combined with the monitoring data of electricity consumption is more meaningful.

Ministry of Housing and Urban-Rural Construction of China has carried out an action on energy consumption statistics, energy audit and establishing the Monitoring System for Energy Consumption aimed at supervising the building energy efficiency of the government office buildings and large public building within 32 local areas [5]. Energy monitoring systems are used widely in large public buildings to observe the energy consumption. Data show that by the end of 2013, China has completed more than 5000 building energy consumption monitoring projects. Building energy monitoring and management system may be defined as the measure and control of energy flows through a system, so as to maximize the net benefits to the system. Based on software system and hardware system, it involves the collection, analyze and monitoring of information on energy use, and the identification, evaluation and implementation of energy saving measures [6]. Building energy monitoring and management system have provided important support for studying energy consumption of HVAC system, which could promote energy saving of air conditioning system and improve the operational management level.

In this paper, the electricity consumption of two buildings that have VRF and centralized air conditioning system were analyzed respectively, and some conclusions on the performance such as adjustability and energy saving effect of two air conditioning system were made.

2. Description of the chiller system and data envelopment analysis

2.1. Composition of electricity consumption

Fig.1 is model of electricity consumption for the building energy monitoring and management system involved in this paper. Dates of subentry of electricity consumption (including lighting-socket system, air conditioning system, power system and others) can be derived from the building energy monitoring and management system. Then buildings electricity com-position could be analyzed based on these dates.

2.2. Rate of electricity consumption of air conditioning system

For office building, the electricity consumption of air conditioning system and lighting-socket system are the main part of total electricity consumption. Electricity consumption of lighting-socket system mainly depends on building usage, named occupancy load rate. However, forms of air conditioning system, outdoor meteorological parameters, building cooling load and efficiency of all equipment of AHU have effects on the electricity consumption of air conditioning system. Hence, rate of energy consumption of air conditioning system can be used to compare and analyze electricity consumption of different forms of air conditioning system. Rate of energy consumption of air conditioning system (R) means the ratio of energy consumption of air conditioning system

(W_{HVAC}) with total energy consumption (W_{total}).

$$R = \frac{W_{\mathrm{HVAC}}}{W_{\mathrm{total}}} \tag{1}$$

Where R is rate of electricity consumption of air conditioning system, W_{HVAC} is electricity consumption of air conditioning system, W_{total} is total electricity consumption. Rate of energy consumption of air conditioning system can be divided into daily, monthly, and yearly rate of energy consumption of air conditioning system according to different statistical period. Date of electricity consumption of a building and its air conditioning system can be derived from building energy monitoring and management system.

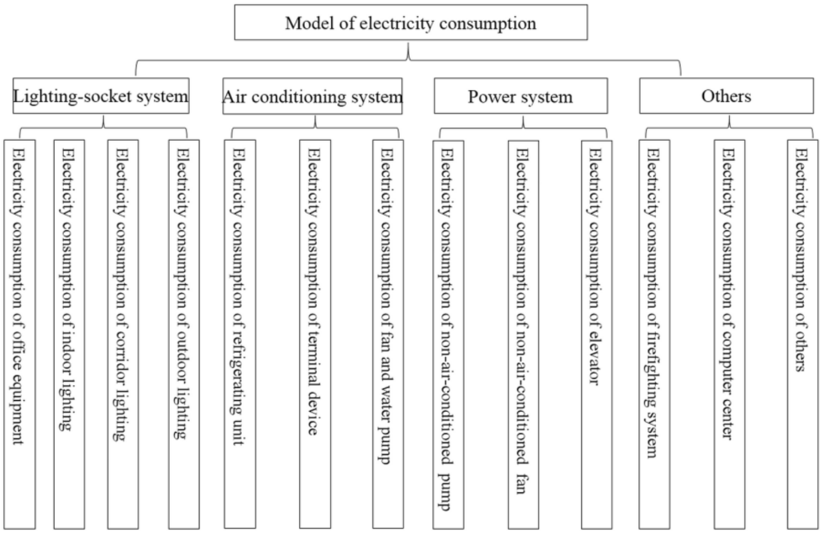

Fig. 1. Model of electricity consumption.

2.3. Occupancy load rate

Design of air conditioning system mainly relies on the most annual unfavorable climate condition which just occupies 1% of one year. At the same time, equipment capacity multiplies by a safety factor. These factors lead to the result that the actual operational process of air conditioning systems are running under partial load in most of the time. Hence, it is critical to adjust AHU operational parameters according to the variation of cooling load. A typical working day in July is selected to analysis electricity consumption of VRF air conditioning systems and centralized air conditioning systems. Outdoor climate is the most stable factor, followed by the indoor equipment and the usage of human is the most unstable factors that can affect building cooling load [7]. Therefore, main factor of affecting power consumption of air conditioning is the cooling load, and the outdoor temperature and humidity is the secondary factor. For the convenience of comparative analysis, a regulation that 6:00~18:00 is working time and 19:00~5:00 is non-working time is made according to laws of the running time of the air conditioning system. The correlation between rates of lighting system and occupant density is strong [8].Therefore, we can estimate the occupancy load rate by electricity consumption of lighting-socket system, namely occupancy load rate i:

$$i = \frac{W_{\mathrm{w}} - W_{\mathrm{n,min}}}{\max[W_{\mathrm{w}} - W_{\mathrm{n,min}}]} \times 100\% \tag{2}$$

Where, i is the personnel load rate of building; W_w is electricity consumption of building in working time, kWh; $W_{n,min}$ is basic electricity consumption of building, caused by the running of the office equipment in non-work time, kWh.

2.4. Partial correlation coefficient

The partial correlation coefficient indicates a pure correlation between the dependent variable y and the independent variable x_j. The linear correlation is obvious if the partial correlation coefficient is greater than 0.5. As for this paper, the partial correlation coefficient of i and R directly reflects linear relationship between rate of electricity consumption of air conditioning system and occupancy load rate. Partial correlation coefficient can be used to describe the adjustability of two systems. Indoor occupants have certain ability to adapt to the environment, namely the human thermal comfort feeling in a range is acceptable [9]. When the rate of electricity consumption of air conditioning system is delayed one hour, the partial correlation coefficient can be obtained by (3), (4), (5).

$$r_{xy}=\frac{\mathrm{cov}(x,y)}{\sqrt{\mathrm{var}(x)\,\mathrm{var}(y)}} \tag{3}$$

$$r_{xy,z}=\frac{r_{xy}-r_{xz}r_{yz}}{\sqrt{(1-r_{xz}^2)(1-r_{yz}^2)}} \tag{4}$$

$$r_{xy,zq}=\frac{r_{xy,z}-r_{xq,z}r_{yq,z}}{\sqrt{(1-r_{xq,z}^2)(1-r_{yq,z}^2)}} \tag{5}$$

Where, x is the occupancy load rate; y is the rate of electricity of air conditioning system; z is the outdoor temperature; q is the outdoor humidity.

3. Results and discussion

3.1. Electricity composition of office buildings in campus

Information about location, function, building area, air conditioning area and type of air conditioning is presented in Table 1.

Table 1. The main information about researched buildings.

Building	Location	Function	Number of people	Building area(m2)	Air conditioning area(m2)	Type of air conditioning
Building 1	Dalian	office	147	8514	7662	VRF
Building 2	Dalian	office	729	36500	32850	Centralized

Dalian is located in North Temperate Zone and belongs to monsoon continental climate. August is warmest when the average temperature is around 24℃. The coldest day is in January when the average temperature is about -4.5 ℃. Mid November to early April is heating period and June to August is cooling season. Dates about subentry of electricity consumption for two buildings is presented in Table 2, Fig. 2 and Fig. 3.

(1) For building 1 and building 2, electricity consumption of lighting-socket system and air conditioning system is the main part of total electricity consumption. While power and other system account for a small part.

(2) Compared with air conditioning system, electricity consumption of lighting-socket system is stable due to the reason that lighting-socket system is correlate with occupancy load rate.

(3) As the temperature increases, electricity consumption of air conditioning system increases significantly.

(4) In summer, rate of electricity consumption of VRF air conditioning system is 0.45; rate of electricity consumption of centralized air conditioning system is 0.52.

Table 2. Subentry of electricity consumption.

Building	Electricity composition	June	July	August	Summer
Building 1	Lighting-socket system(kWh/m^2)	1.28	1.28	0.91	3.47
	Air conditioning system(kWh/m^2)	0.49	1.52	1.66	3.67
	Power system(kWh/m^2)	0.04	0.03	0.02	0.09
	Others(kWh/m^2)	0.14	0.11	0.10	0.35
Building 2	Lighting-socket system(kWh/m^2)	3.02	3.02	2.47	8.51
	Air conditioning system(kWh/m^2)	0.82	3.41	2.66	6.89
	Power system(kWh/m^2)	0.30	0.33	0.31	0.94
	Others(kWh/m^2)	0.01	0.01	0.01	0.01

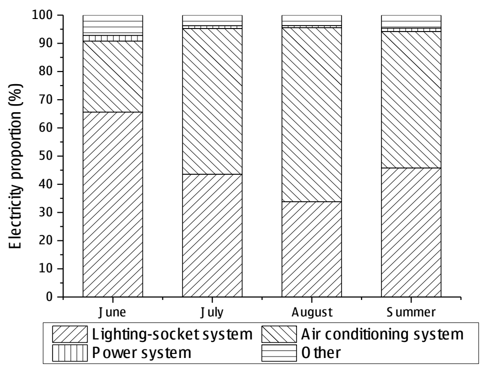

Fig. 2. Monthly disaggregation of electricity consumption of building 1.

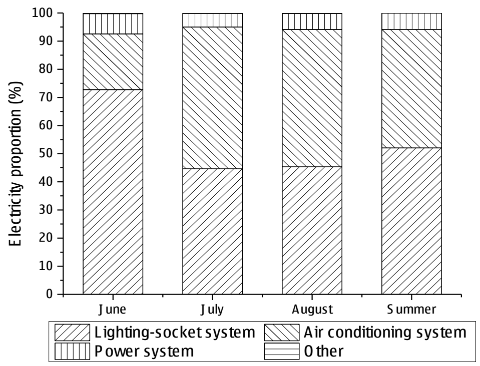

Fig. 3. Monthly disaggregation of electricity consumption of building 2.

Electricity consumption of air conditioning system and lighting-socket system is the main part of office building's total electricity consumption. Electricity consumption of lighting-socket system mainly depends on occupancy load rate, however, electricity consumption of air conditioning system is related to outdoor climate and efficiency of equipment of air conditioning system. Therefore, it has great significant to analysis operational characteristics of air conditioning system and optimize operational strategy.

3.2. Analyze of adjustability of two air conditioning systems

Rate of electricity consumption of air conditioning system varies with occupancy load rate during working time 8:00~17:00 in building 1 as shown in Fig. 4, which shows that VRF air conditioning system is flexible to adjust operating parameters of units adapting to cooling load. Fig. 5 shows correlation between rate of electricity consumption of air conditioning system and occupancy load rate of building 2 equipped with a centralized air conditioning system. The air conditioning system begin to run at 7:00 and stop at 16:00. As a contrast, occupancy load rate of building 2 is closed to building 1, while rate of electricity consumption of air conditioning system remain at a relatively stable range during 8:00~17:00, especially in case that occupancy load rate is decreased obviously and rate of electricity consumption of air conditioning system is increased at noon.

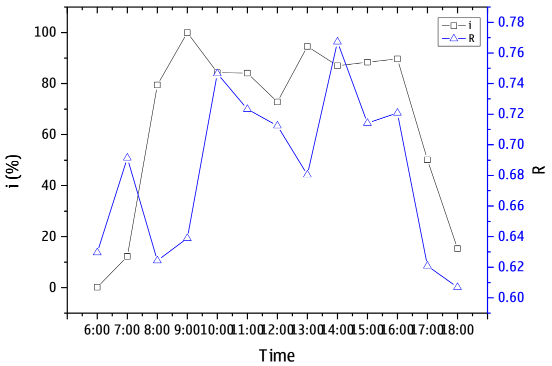

Fig. 4. Correlation between *R* and *i* in building 1.

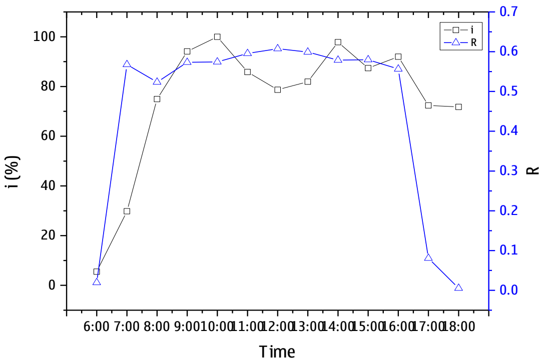

Fig. 5. Correlation between *R* and *i* in building 2.

The linear correlation relationship of building 1 between rate of electricity consumption of air conditioning system and occupancy load rate is significant, as shown in Table 3. However, building 2 is just contrary to building 1. VRF air conditioning system can control each indoor unit independently according to changes of cooling load, which reflect its characteristics of flexible adjustability. Therefore, VRF air conditioning system could reduce the electricity consumption by operational mode of distributed control. For the operational mode of the artificial control, centralized air conditioning system usually can not realize independent control in each room. In addition, lacking of optimal control strategies determines its adjustability is poorer. Thus, adjustability of VRF is better than centralized air conditioning system in this paper.

Table 3. Partial correlation coefficient of two building.

Building	Types of sir conditioning system	r	Remarks
Building 1	VRF air conditioning system	0.65	Linear correlation
Building 2	Centralized air conditioning system	0.38	Nonlinear correlation

3.3. Analyze of intensity of electricity consumption of air conditioning system

Temperature and CO_2 concentration of 3 test points that were selected in a room in building 1 and building 2 respectively were tested in forenoon and afternoon and table 4 is test results. Results shows that indoor environment parameters of two buildings with VRF and centralized air conditioning system respectively are basically the same in summer.

Table 4. Test results of temperature and CO2 concentration.

	Test points	A room in building 1 (45m^2)		A room in building 2 (50m^2)	
		Temperature(℃)	CO2 concentration(ppm)	Temperature(℃)	CO2 concentration(ppm)
Forenoon	1	25.50	483	25.60	159
	2	25.60	489	25.80	313
	3	25.90	499	26.10	439
Afternoon	1	24.40	605	25.40	496
	2	25.10	624	25.60	575
	3	25.10	567	25.70	600
Average value		25.27	544	25.70	430

Table 5. Electricity consumption of air conditioning system in summer.

Building	Per unit area electricity consumption of air conditioning system (kWh/m2)			
	June	July	August	Summer
Building 1	0.49	1.52	1.66	3.67
Building 2	0.82	3.41	2.66	6.89

Rate of electricity consumption of two air conditioning system is 0.48, 0.42 respectively; While per unit area electricity consumption of two air conditioning system is 3.67 kWh/m^2, 6.89 kWh/m^2 respectively as shown in Table 5. Therefore, both VRF air conditioning system and centralized air conditioning system have great potential for energy savings. The setting temperature of air conditioner could be adjusted according to people's willingness for the flexible adjustability of VRF air conditioning system, which result in electricity consumption increased. While for centralized air conditioning system, lack of optimal operation strategies and methods of adapting to cooling load change are main reason. Therefore, on aspects of energy saving operation, enhancing awareness of energy saving is the main factor affecting the operation of VRF air conditioning system; optimizing operational strategy and improving the efficiency of AHU is the main way to reduce electricity consumption of centralized air conditioning system.

4. Conclusions

In this paper, electricity consumption of two buildings that are equipped with VRF and centralized air conditioning system are analyzed, according to the monitoring data derived from building energy monitoring and management systems. Then adjustability and energy saving potential are compared based on relationship between rate of electricity consumption of air conditioning system and occupancy load rate. The major findings can be summarized as follows:

(1)Electricity consumption of lighting-socket system and air conditioning system is main part of total electricity consumption in campus office buildings. Electricity consumption of lighting-socket system mainly depends on occupancy load rate, however, electricity consumption of air conditioning system is related to outdoor climate and efficiency of equipment of air conditioning system. Therefore, it has great significant to analyze operational characteristics of air conditioning system and optimize operational strategy.

(2)The partial correlation coefficient between occupancy load rate that is estimated by electricity consumption of lighting-socket system and rate of electricity consumption of air conditioning system is calculated. Result shows that adjustability of VRF is better than the centralized air-conditioning system.

(3)Both VRF air conditioning system and centralized air conditioning system have great potential for energy savings. In terms of factors affecting energy-saving operation, temperature of air conditioner should be set reasonably for VRF air conditioning system, and improving operational efficiency of equipment, optimizing operational strategy are basic way to reduce electricity consumption for centralized air conditioning system.

Conclusions of this paper are based on two buildings with VRF and centralized air conditioning system respectively, which is not universal. The energy consumption characteristics of two kinds of air conditioning system needs further research.

Acknowledgements

This research was supported by the Key Projects in the National Science & Technology Pro-gram in the Twelfth Five-year Plan Period of China (Grant No. 2011BAJ03B12-3, 2013BAJ10B02-03), the Fundamental Research Funds for the Central Universities of China (DUT14ZD210), the National Natural Science Foundation of China (Grant No. 51378005), and the Fundamental Research Funds for the Central Universities of China (DUT12RC (3)25).

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