INVESTIGATION ON AIR-CONDITIONING ENERGY CONSUMPTION OF A TYPICAL COMMERCIAL BUILDING COMPLEX

Qinghai Luo
College of Architecture and Resource, Nanhua University, Hengyang, Hunan 421001, China

Guangfa Tang and Wensheng Huang
College of Civil Engineering, Hunan University, Changsha 410082, China

(Received 13 November 2004; Accepted 13 March 2006)

ABSTRACT

The air-conditioning energy consumption of a typical commercial building complex was investigated in four aspects: the component of energy consumption, cooling load parameters, coefficient of performance and coefficient of water conveyance. Suggestions on improving the air-conditioning systems were proposed as follows; (1) combining the south and the north primary system into a unit one, (2) adding frequency control for water pump, (3) modifying the running scheme of fresh air handling units, (4) intensifying the management and maintenance of the system.

1. INTRODUCTION

Since energy consumption of air conditioning accounts for 30~50% of the total value of commercial building, energy efficiency has been obtained increasing attention. Investigation on air-conditioning energy consumption is the basis of energy conservation. Some developed countries have obtained a great deal of statistical results on these aspects, while in China, small scale investigations were only focused on typical commercial buildings in Beijing and Shanghai. The climate difference is remarkable in different regions of China, so it is indispensable to investigate air-conditioning energy consumption of commercial buildings in other regions. Air-conditioning energy consumption of a typical commercial building complex was investigated in summer and winter in Changsha, and some suggestions were proposed to improve the air-conditioning system.

2. GENERAL DESCRIPTION OF THE SYSTEM, ITS OPERATION AND MAINTENANCE

2.1 Air-conditioning System

This is a commercial building complex integrating a hotel, office rooms, council-chambers and other recreation rooms. It consists of two tower buildings (north and south) on the skirt building. The total building area is 52 000 m^2, and 45 660 m^2 over the ground. Hereinto, total area of 4 454.4 m^2 of the No. 11-15 floor of the south tower building have not come into dealing yet. The working hours of office rooms are 8:00-18:00 weekdays, and guest room ratio of the hotel is over 60%.

There are two central air-conditioning systems for the north and south tower building respectively, and air-conditioning loads of the skirt building floors are also included in the north and south systems respectively. The south system adopts three centrifugal refrigerating machines and three oil-burning boilers, while the north system adopts lithium-bromide absorption refrigerating units. In addition, two screw air-cooling heat pump units were set to supply air-conditioning load of multifunction hall, dancing hall, bowling alley in the skirt building. The south and the north air-conditioning systems are both double-tube primary pump system, and every machine was matched with one water pump for chilled water and cooling water systems, and an auxiliary water pump is also set for two systems respectively.

2.2 Operation and Maintenance Description

The operation of the air-conditioning system presented some phenomena as follows:

(1) Some important equipment were left unused for a long term.

System began operating since 1998, but the total running time of the two heat pump units and matching water pumps was only 360 h. The three centrifugal refrigerating units never operated simultaneously, even two of them were not often operating simultaneously; and the situations of oil-burning boilers were alike. Only one cooling water pump of north system can meet the conveyance demand of the north system.

(2) The fresh air systems could not work efficiently due to short of management.

The fresh air fans were equipped dispersedly, and not controlled by the auto-control system. Each floor of the skirt building was furnished with one or two fresh air fans, which never ran while the energy consumption of air-conditioning systems was investigated for several months. The majority of fresh air louvers were also shut. Each floor of the tower building was furnished with one fresh air fan, which was controlled by waiters according to the schedule, viz. office rooms: 8:00-18:00 of weekdays; guest rooms: 8:00-24:00 of each day.

(3) Temperature control switches were random set.

In Changsha, the indoor design temperature is normally 24-26°C in summer, and 16-18 °C in winter. In the presented air-conditioning systems, the temperature of return air was manipulated via the central process unit of the auto-control system, however, the temperature regulators matched with fan-coil units were set disorderly. The temperature switches were almost set to utmost in many rooms. The set points of temperature switches were even lower than 20 °C in summer, however, higher than 24 °C in winter in some rooms, and these switches actually lost its regulating functions.

(4) The mechanical air supply and exhaust system was furnished in a basement, but never operated.

(5) Maintenance was wanting. Only water systems were checked and maintained every year periodically. However, air-line systems were never cleaned, dust deposit was considerable therefore.

3. INVESTIGATION OF ENERGY CONSUMPTION OF AIR-CONDITIONING SYSTEM

3.1 Methods

The testing periods were from July 30, 2003 to Aug 28, 2003 in summer, from Dec 15, 2003 to Jan 10, 2004 in winter.

Considering that the normal office hours is 8:00-17:00 in the present building, and that air-conditioning load of office zone accounted for a considerable proportion of the whole system, five typical testing times were selected as: 8:30, 10:30, 12:30, 12:00, 16:00. Because spots of collecting data were distributed in several floors, and all investigating data were artificially collected, the actual collecting times might be advanced or lagged comparing with the above basic testing time, but the departure times were less than 15 minutes.

The tested parameters included: (1) the dry bulb temperature in and out doors; (2) the power input of motors matched with the chilled water units, chilled water pumps, cooling water pumps, cooling towers and other terminal air-conditioning equipments; (3) the oil consumption of the boilers and direct-fired absorption units; (4) the temperatures and flow rates of the cold and hot water. The parameters of temperature and flow rates were auto-documented by the auto-controllers, and the oil consumption was calculated with the scale variation of oil level gauges.

3.2 Analysis on Energy Consumption

The air-conditioning energy consumption was analyzed on four aspects: (1) the distribution of energy consumption, (2) cooling load parameters, (3) coefficient of performance and (4) coefficient of conveyance of chilled water.

3.2.1 Distribution of energy consumption

The distribution of energy consumption may provide basic data for energy conservation and system improving. The power consumption variations are presented in Fig. 1 for the north system and the south system. The energy consumption proportions of equipments are shown in Table 1.

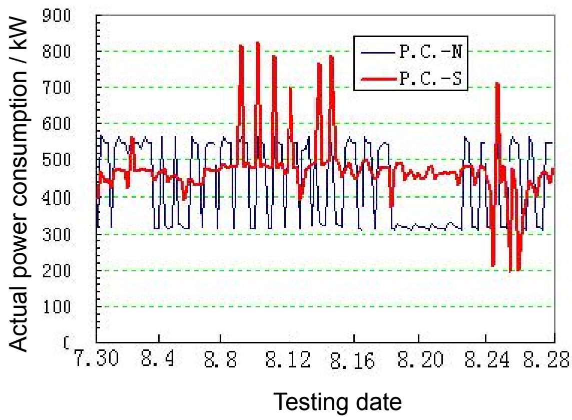

Fig. 1: The total power consumption variations of the north and the south subsystem

Table 1: Ratios of power consumption to cooling load and corresponding distributions (kW/kW)

Items		Total power consumptions	Distribution of power consumption			
			Chiller units	Chilled water systems	Cooling water systems	Terminal devices
South subsystem	Actual mean values	0.444	0.243	0.048	0.071	0.071
	Design indexes	0.304	0.198	0.039	0.044	0.022
North subsystem	Actual mean values	1.012	0.705	0.103	0.153	0.050
	Design indexes	0.366	0.168	0.040	0.083	0.076

The distribution of energy consumption presented some properties as follows:

(1) The energy consumption of the chilled water units accounted for more than 55% of the total value, and also fluctuated remarkably, so they are the keys to energy conservation of air-conditioning systems. The energy consumption proportions of centrifugal refrigerating units were obviously less than that of direct-fired refrigerating units. The total power consumption of the north system was larger than that of the south system for 46.76% testing time, while the air-conditioning area of the north building was merely 22.53% that of the south building.

(2) The energy consumption of the water system was another important component, and accounted for about 25% of the total value. The constant flow water system could keep the energy consumption relatively steady, and thus it is of long-term significance to decrease the energy consumption of the water system.

(3) The energy consumption reached the highest level in noon, and its the variation depended on the distribution of air-conditioning load, while the chiller performance was also an important factor to this variation.

3.2.2 Cooling load parameter

As can be seen from Table 2, the actual cooling load was far less than the design load, and the maximum ratio was even less than 64% at all testing times. The cooling load of a commercial building complex presented four properties as follows:

Table 2: Cooling load parameters (Wm^{-2})

Subsystems	Actual maximum	Design value	Ratios
South	64.65	102.23	63.24%
North	52.54	141.05	37.25%

(1) The design load was on the high side.

The design load was obviously higher than the recommended load (58~93Wm^{-2}) [6], and the excessively high design load directly led to two disadvantages for energy efficiency:

i. Increasing the investment cost of the air-conditioning system and decreasing the utilization ratio. Only two of three centrifugal refrigerating units of the south buildings might operate simultaneously at best, and the two heat pump units were unused completely.

ii. The refrigerating efficiency was lower since the refrigerating systems were running with part load for long term. As for the north air-conditioning system, the largest utilization ratios of chillers was only 48% calculated by rated refrigerating capacity, which directly affected the energy efficiency ratio of the air-conditioning system.

(2) The actual cooling load fluctuated considerably.

The multifunction of building complex brings the cooling loads variation with different air-conditioning region, and peak load times are also inconsistent, so it is quite important for energy conservation to understand the variation and distribution properties of cooling load. As can be seen from Fig. 2, the cooling load trend-lines of the south and the north system were similar, though corresponding fluctuation scopes were different. Operators should adjust the number of running machines according to the cooling load variation, thus air-conditioning systems would run in the cope of rated load, and keep efficient.

(3) The load peak came in lunchtime, which reflected the load variations with time of commercial building complexes. Fig. 3 illustrates that cooling load increased slowly with outdoor dry bulb temperature rising.

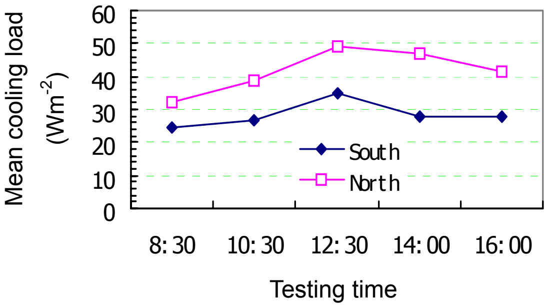

Fig. 2: Actual mean cooling load variations with testing times

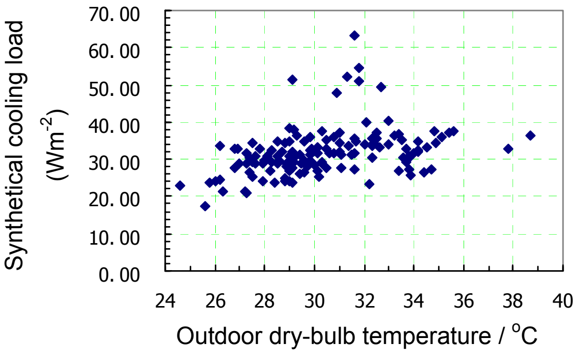

Fig. 3: Actual cooling loads variation with outdoor dry-bulb temperature

3.2.3 Coefficient of performance

Fig. 4 reflects the actual COP trend-lines and mean values of the north (COP-N) and the south (COP-S) air-conditioning system. Equipments were selected reasonably, for the design COP (5.04) of centrifugal refrigerating units was 14.55% higher than the recommended minimum value (4.4), and the design COP (3.04) of the north system also reflected high performance of direct-fired absorption units. But the actual COPs of chillers were dissatisfying, the mean value (3.99) of the south system was 79.17% of the design value (5.04), and the mean value (1.54) of the north system was only 50.66% of the design value (3.04).

Fig. 5 and Fig. 6 illustrate that COP trend-lines with changing refrigerating capacity were dissimilar for different units. The COP of centrifugal refrigerating units increased slowly, and the actual refrigerating capacity per unit focused in the range of 800~1250 kW with corresponding COP increasing range of 28%. The COP of direct-fired absorption units increased linearly, and the actual refrigerating capacity per unit focused in the range of 180~500 kW with corresponding COP increasing range of 160%. As for actual range of cooling load, a centrifugal refrigerating unit was superior to a direct-fired absorption unit in the aspects of energy efficiency and performance stability.

In sum, the actual COP decline of the refrigerating units was the main reason for the power consumption increase of the air-conditioning system. Another reason was that the power consumption of the water system was on the high side. As can be seen from Table 1, the actual power consumption average of the south and the north water systems was 1.434 and 2.081 times of the design value respectively. Devices of the water system include chilled water pump, cooling water pump and cooling tower. The energy consumption of the cooling tower was the lowest, and its effect was the smallest.

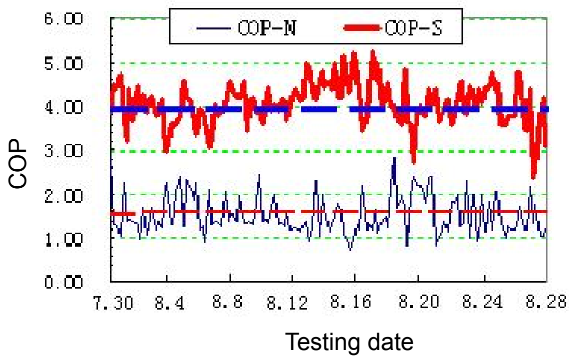

Fig. 4: The actual COP variations with testing time and mean values

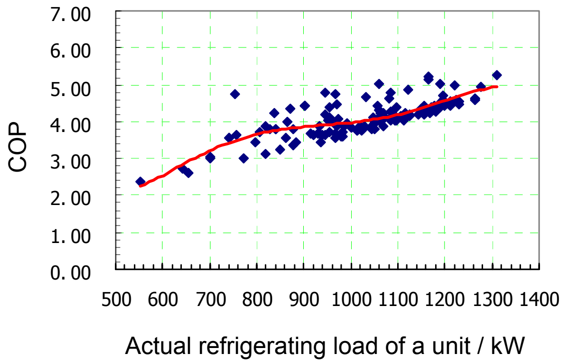

Fig. 5: COP variation with the actual refrigerating load of a single centrifugal unit

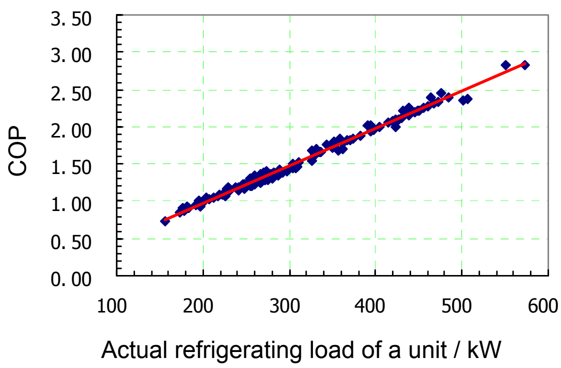

Fig. 6: COP variation with the actual refrigerating load of a single direct-fired unit

3.2.4 Conveyance coefficient of the water system

Constant flow water systems were adopted, and each refrigerating unit matched a water pump, which power consumption was independent of the variation of sensible heat conveyance. As can be seen from Table 3, the design of the water systems were not up to the criterion of energy conservation, and the design sizes of the chilled water pumps is on the large side, the design water conveyance coefficients was less than the criterion value. Analogous shortages also existed in the cooling water systems [6]. The actual cooling load of the south system could not reach the rated refrigerating capacity of one centrifugal refrigerating unit, and the direct-fired absorption units of the north system also operated with derated refrigerating capacity. The constant flow water systems always operated with part cooling load, whereas the power consumption kept at the design value all the time, which is just the shortcoming of a constant flow water system.

Table 4 lists the mean temperature differences between chilled water supply and return at different testing times. It is well known that the flow rate of a constant flow water system keeps constant, and that the variation of cooling load can be matched by the variation of temperature difference between supply and return water. While the cooling load is decreasing, the situation with large flow rate and small temperature difference is inevitable in the system. In the presented air-conditioning system, the actual cooling loads and their corresponding departures form design indexes were different remarkably, and the corresponding temperature differences between supply and return water were also different considerably.

As can be seen from Table 3 and Table 4, the water conveyance coefficients may meet the demand of criterion and further significantly decrease the energy consumption on the refrigerating load conveyance, if the problem of large flow rate and small temperature difference could be raveled out. Similarly, increasing the temperature difference between cooling water supply and return would decrease the power consumption of the cooling water system.

4. SUGGESTIONS ON IMPROVING THE AIR-CONDITIONING SYSTEMS

Based on the energy consumption data, the potentials of energy conservation were large in the air-conditioning systems. Some measures were proposed to improve the energy efficiency and management of the air-conditioning system.

Table 3: Mean conveyance coefficients of the water systems

	Testing times	Chilled water pump		Cooling water pump	
		Subsystem-S	Subsystem-N	Subsystem-S	Subsystem-N
The actual mean values	8:30	16.50	9.92	16.50	6.39
	10:30	17.76	10.37	17.76	8.14
	12:30	19.19	10.65	19.19	9.57
	14:00	18.57	10.38	18.57	9.23
	16:00	18.62	9.95	18.62	8.39
Design values		25.58	25.20	25.58	13.75

Table 4: Mean temperature difference between chilled water supply and return (^{o}C)

Testing time	The south system				The north system			
	Low region	Middle region	High region	Mean value	Low region	Middle region	High region	Mean value
8:30	3.28	3.37	2.37	3.11	0.85	1.34	1.75	1.20
10:30	3.68	3.27	1.94	3.11	0.91	1.65	2.01	1.38
12:30	3.99	3.43	2.40	3.39	1.00	1.81	2.11	1.50
14:00	3.79	3.35	2.84	3.38	0.95	1.83	2.12	1.49
16:00	3.72	3.46	2.76	3.39	0.89	1.77	1.93	1.40

(1) Combining the south and north subsystem into a united system

The combination of the south system with the north system means modifying the link pipe between the two systems and stop operating the direct-fired units and the matched water pump, thus the refrigerating load supplied initially by the north system can be taken on by the south system.

i. Based on the energy consumption analysis, it indicated that the energy efficiency of the centrifugal units was markedly higher than that of the direct-fired units, whereas the utilization ratio was converse. After the direct-fired units ceased operation, the combining system can raise the utilization ratio of the centrifugal units, and raise the energy efficiency ratio further. The maximum of actual total cooling load was 3 MW, which was less than the total rated refrigerating capacity of the three centrifugal units, even adding the design cooling load of unused floor 11~15 (4454.4 m^2) of the south building.

ii. The actual water flow rate of chilled water pump exceeded the demand corresponding to the cooling load, only recycle water pump of the primary south system will operate after combining the two primary systems, so the sensible heat conveyance of single water pump may be increased, and the water conveyance coefficient rise further.

iii. The modification was technologically feasible to the situation of the primary systems.

(2) Adding frequency control to water pumps

The design sizes were obviously on the large side. It is a simple and feasible method of energy conservation to change the existing constant water flow system into a variable one by adding frequency control to water pumps after combination.

(3) Making the best of fresh air handling units

The disorder operation resulted in decreased functions of fresh air handling units, and modifying the running scheme can improve the indoor air quality.

(4) Intensifying the management and maintenance

Maintaining periodically can help to operate equipments well, and further to raise energy efficiency of the air-conditioning system.

5. CONCLUSIONS

It is concluded that main air-conditioning energy consumption parameters of a typical commercial building complex, namely energy consumption distribution, load parameter, energy efficiency ratio and water conveyance coefficient, were all inferior to the recommended value of the national air-conditioning energy conservation criterion.

Suggestions on improving the air-conditioning systems are proposed as follows: (1) combining the south and north system into a unit one; (2) adding frequency control to water pumps; (3) making the best of fresh air handling units; and (4) intensifying managements and maintenance.

As the first investigation on the air-conditioning energy consumption of a typical commercial building complex in Changsha, it provided reference data for designing, improving and managing air-conditioning systems of analogous commercial buildings.

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