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An Investigation on Energy Consumption of Air Conditioning System in Beijing Subway Stations

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Abstract

This paper initially depicted on the energy consumption of air conditioning systems in Beijing subway stations. An investigation was conducted among ten underground subway stations to the examination of practical operation conditions of their cooling units. The overall field testing included information such as air conditioning system formation, equipment types, system operation parameters, energy consumption and system operation efficiency. The results showed that the COP value of refrigerators in the tested subway stations were generally high at about 4.4 in average. Nevertheless, the mean EER and SCOP values were nearly 27% and 48% lower than the average COP value due to the large amount of energy consumption in water pumps, cooling towers and fans. There was a big difference among each station in terms of the instantaneous power consumption of air conditioning systems. The most energy consuming station was nearly seven times higher than the least one. It was observed that there was a lack of maintenance and system operation strategy for these underground air condition systems. A promising potential for energy saving was found out within the air conditioning systems in Beijing subway stations.

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Keywords: subway station ; air conditioning system ; energy consumption

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Nomenclature

COP	Coefficient of Performance of refrigerator
EER	Coefficient of Performance of cooling source
SCOP	Coefficient of Performance of air conditioning system
PSD	Platform Screen Doors system
Qc	Cooling capacity
Pc	Instantaneous power consumption of refrigerator
Pp	Instantaneous power consumption of chilled and cooling water pumps
P_T	Instantaneous power consumption of cooling towers
P_F	Instantaneous power consumption of supplying and exhausting fans

1. Introduction

In China, the public transportation system has undertaken a rapid development in this decade. Through the government propaganda of "energy saving and emission reduction", most people are encouraged to take the public transportations, especially as subway. According to the advanced report from China Association of Metros, there are 26 cities that have the urban rail transit with a total amount of 116 subway lines, almost 3600 km at the end of year 2015. The number of operating subway stations were 2236 in total. There are 13.8 almost billion passengers who chose urban rail transit as their regular traveling tool in 2015. The average daily passenger volume was almost up to 6 million in Beijing, Shanghai and Guangzhou. Moreover, in the next five years, the total distance of new construction subway lines will be beyond 3000km [1].

On the other hand, the increased subway volume requires much more energy for operation. Some research has already reported that part of air conditioning system in the South China could even consume half energy of the total "non-traction energy use" in summer [2], and the energy consumption may become higher than that due to "traction energy use" in some extreme condition [3]. Another study highlighted that the air conditioning system consumed 31% energy of the annual subway energy use in Beijing and Shanghai [4]. Obviously, reducing energy consumption of air conditioning systems is one of the most effective ways to tackle high energy demand of subway systems.

Currently, most studies only focused on the numerical simulation of air conditioning system in subway stations [6-7]. Their conclusion and recommendation were somehow very limited in terms of validation because of the insufficient field data and measurements. As a result, it is difficult to conclude a general effective energy-saving strategy from the past studies. This paper initially conducted a serious of filed measurements in the summer of 2016, with the aims to investigate the energy consumption and the operational efficiency of air conditioning systems of 10 subway stations in Beijing. The operation condition of running units and the existing technical barriers were summarized. This study may further provide useful guidance towards energy saving in Beijing subway stations.

2. Experimental Set Up and Testing Method

This investigation aims to test the real operation condition and system efficiency of air conditioning systems in Beijing subway stations. Through this investigation, the existing operational barriers and energy saving potential of air conditioning system will be identified and evaluated. The testing of 10 subway stations were selected by the Metro Operation Department, from Line 6,7,8,9,10 and 14. Most of the stations were constructed with central cooling units. The detailed information of the stations and their cooling units was shown in Table 1.

Table 1. Station and cooling units

Station	Station form	Platform	Open time	Cooling units
A	Transfer	Island	2012	Water chiller
B	Non-transfer	Island	2012	Water chiller

C	Non-transfer	Island	2014	Water chiller
D	Non-transfer	Side (PSD)	2012	Water chiller
E	Non-transfer	Island	2011	Coolant directly expanding
F	Transfer	Island	2011	Water chiller
G	Transfer	Island	2012	Water chiller
H	Non-transfer	Island	2012	Water chiller
I	Non-transfer	Island	2012	Water chiller
J	Non-transfer	Island	2014	Water chiller

The selected stations were all equipped with cooling towers except station E. The temperature of cooling water could be directly detected because there was no external insulation layer around the cooling water pipe. The temperature of chilled water was measured through the removal of external insulation layer. Besides, the parameters recorded by refrigerator panel was collected, such as compressor suction and exhaust pressures, units load ratio, inlet and outlet water temperatures. Other parameters, i.e. chilled and cooling water temperatures, instantaneous energy consumption (fans, refrigerators, pumps and cooling towers), and temperature of hall and platform, were measured through dedicated instruments. The detailed testing method was displayed in Table 2. Some field testing photos shown in Fig. 2.

Table 2. Testing methods and parameters

Testing methods	Parameters
Temperature recorder	Chilled/cooling water inlet and outlet temperature
Ultrasonic flowmeter	Chilled and cooling water flux
Power clamp	Instantaneous power consumption of refrigerators, fans, pumps, cooling towers
Refrigerator panel	Evaporating and condensing temperature/pressure

a b

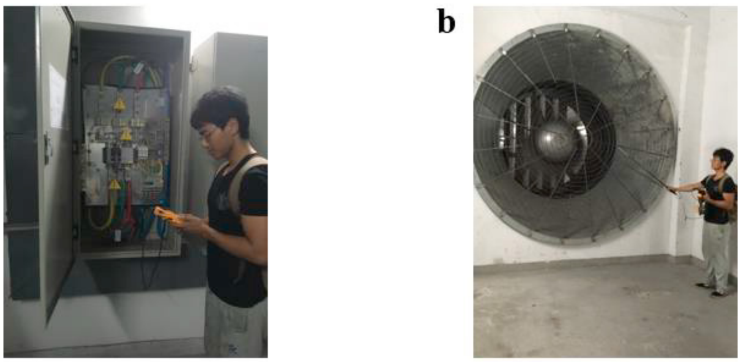

Fig.1 Field testing photos

3. Results and Discussion

3.1. Evaluation theory

In this paper, three key parameters [5] are calculated to evaluate the energy efficiency of air conditioning systems. They are the Coefficient of Performance of refrigerator (COP), the Coefficient of Performance of cooling source (EER) (including chilled water pumps, cooling water pumps, cooling towers), and the Coefficient of Performance of whole air conditioning system (SCOP)(including supplying and exhausting fans). The calculation formulas are presented as follows:

$$COP = \frac{Q_c}{P_c} \tag{1}$$

$$EER = \frac{Q_c}{P_c + P_P + P_T} \tag{2}$$

$$SCOP = \frac{Q_c}{P_c + P_P + P_T + P_F} \tag{3}$$

where, Q_C is the refrigerating capacity, calculated by the temperature difference between supply and return chilled water. P_C is the instantaneous power consumption of refrigerator. P_P represents the instantaneous power consumption of chilled and cooling water pumps. P_T is the instantaneous power consumption of cooling towers. P_F is the instantaneous power consumption of supplying and exhausting fans.

3.2. Efficiency of air conditioning systems

The testing results for the air conditioning systems in each station is presented in Table 3. It is found that the COP values ranged from 3.0 to 6.0. The average value was 4.4. The lowest value of 3.0 appeared in the subway station I, whereas the peak COP value showed in the station H. The EER values ranged from 2.1 to 4.7 and the average value was 3.2. The highest EER value of 4.7 was found in station D, while the station I had the lowest EER value of 2.1. The SCOP values ranged from 1.1 to 3.6, and the average value was 2.3. Similarly, station I had the minimal value 1.1, while station D and E had the maximal value 3.6. Based on the results above, it can be summarized that the COP values of refrigerators in these subway stations were generally high at about 4.4 in average. Nevertheless, the EER and SCOP values were much lower than COP values because of the great energy consumption of water pumps, cooling towers and fans. Compared with the average COP value, the mean EER and SCOP values was respectively 27% and 48% lower.

Table 3. Station and cooling units

Station	Cooling units	Compressors Power/kW	Pumps &Towers Power/kW	Fans Power/kW	Cooling Capacity/kW	COP	EER	SCOP
A	Water chiller	323	185	212	1626	5.0	3.2	2.3
B	Water chiller	186	67	150	719	3.9	2.8	1.8
C	Water chiller	192	64	135	817	4.3	3.2	2.1
D	1#Water chiller	82	19	33	480	5.9	4.8	3.6
	2#Water chiller	66	19	29	341	5.2	4.0	3.0
E	Directly expand	103	22	25	540	5.2	4.3	3.6
F	1#Water chiller	258	143	82	915	3.5	2.3	1.9
	2#Water chiller	141	82	82	615	4.4	2.8	2.0
G	1#Water chiller	309	154	93	1121	3.6	2.4	2.0
	2#Water chiller	60	26	39	186	3.1	2.2	1.5
H	1#Water chiller	217	137	84	1303	6.0	3.7	3.0
	2#Water chiller	67	65	38	300	4.5	2.3	1.8

I	1#Water chiller	177	49	90	712	4.0	3.2	2.3
	2#Water chiller	32	12	43	95	3.0	2.2	1.1
J	1#Water chiller	207	60	65	773	3.7	2.9	2.3
	2#Water chiller	85	26	33	383	4.5	3.5	2.7

3.3. Instantaneous power consumption

Fig. 2 illustrated the instantaneous power consumption of air conditioning system subentry. It could be observed that there was a big difference among each station. The most energy consuming station was seven times higher than the least one. The power consumption of station A, G and H were relatively higher than other stations. Oppositely, Station D and E had much less energy consumption. Considering that station D was built with platform screen doors system (PSD), the heat transfer between tunnel and platform was cut off. Thus, the cooling load was much lower. The coolant directly expanding air conditioning system in station E was also observed as energy-efficient operation. Station A, G and F were transfer stations with larger area than others. However, Station A and G consumed more energy than Station F. This phenomenon revealed that even large station might have feasible energy saving ways when the energy consumption of pumps, cooling towers and fans of some stations were almost the same as the energy consumption of compressors.

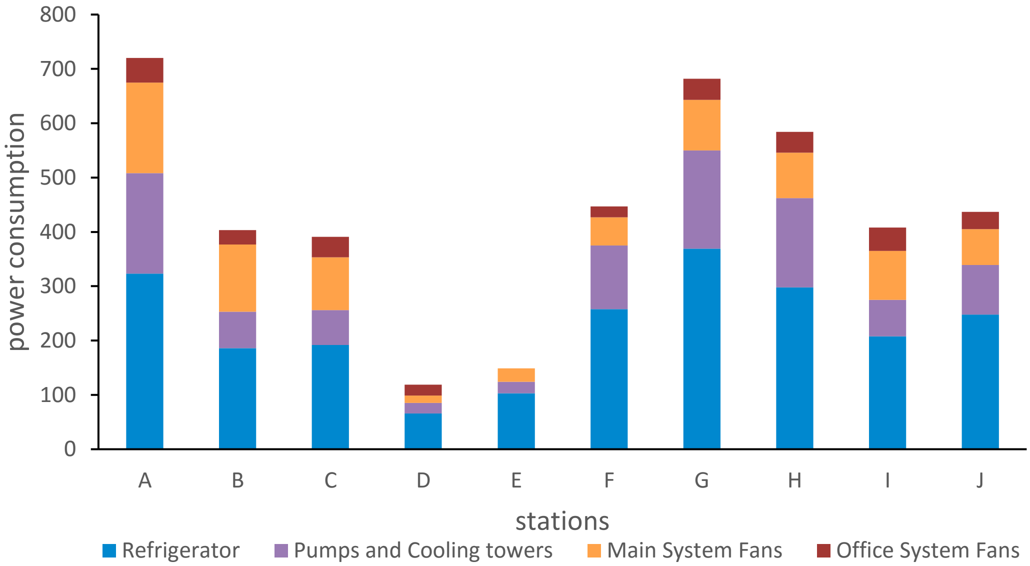

Fig.2 Subentry instantaneous power consumption statistics

3.4. Testing results discussion

From the testing results, it was obviously observed the most energy consuming component were compressors. The efficiency of compressor was determined by system type, cooling load and its own running state. Besides, the power of pumps, cooling towers and fans also resulted in the difference between testing stations. Transfer stations with larger area and cooling load like station A, F and G seemed to consume more energy. However, Non-transfer Station B, C, H, I and J were almost the same as F. This phenomenon explained there would be an urgent need to promote the system efficiency for either transfer stations or non-transfer stations. The main reasons causing the energy waste were put forward:

- Equipment running errors. During the testing, it was found that some refrigerators, pumps and cooling towers were shut down because of running faults. In addition, some meters were lost that resulted in the difficulty of data collection. Other operational problems, such as transducer faults, oversized pump volume and heat exchanger dirty/scaling, also affected the system efficiency. In general, the facilities were extremely lack of maintenance during the operation.

- Energy saving strategy absence. The operation modes of refrigerators and cooling towers were not matched with the station cooling load variation. The set temperature of cooling water outlet were slightly lower than standard, which influenced the final COP.

4. Conclusion

This paper investigated the operational efficiency and energy consumption of air conditioning system in 10 Beijing subway stations. Through the field testing in these stations, physical parameters, such as temperature, humidity, instantaneous power consumption, were collected. System efficiency (COP, EER, and SCOP) and subentry instantaneous power consumption were calculated. The following conclusions could be drawn:

- The testing stations reached a normal average COP level of 4.4. The average EER and SCOP value were much lower than COP value due to the huge energy consumption of pumps, cooling towers and fans.
- It was observed that two stations (D, E) were operated in a condition of low energy consumption and high system efficiency. This is because Station D adopted PSD system and station E were constructed with coolant directly expanding air conditioning system. These two methods may be popularized in other stations.
- Energy-saving operation strategy and facility maintenance for air condition systems in subways station were highly necessary for further research.

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