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Energy Consumption Analysis of Air Conditioning System in Clean Operation Department : a case study of a hospital in Beijing

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ABSTRACT

Based on the investigation of a hospital in Beijing, it is found that the clean air conditioning system of the operation department consumes a large amount of energy per unit area, and the energy consumption of the air conditioning unit is relatively high in winter than in summer. The energy consumption simulation software was used to build the model. After verification, the model is used to simulate and analyze different working conditions based on the requirements of Chinese standards. The results show that the energy consumption of the surgical department is relatively high, and the new standard in China can save 16% compared with the current energy consumption of the surgical department. China's new standard saves 10 percent of energy compared with the old one. This verified energy consumption benchmark model combined with national standards provides ideas for energy consumption quota.

Keywords: operation department, clean air conditioning system, energy consumption simulation, standards comparison.

1. INTRODUCTION

Since the 20th century, total area of public buildings has increased nearly three times in China. According to relevant statistics, the energy consumption level of public buildings is far higher than that of general buildings, which can reach 8~10 times of the latter. Large medical equipment, large flow of people and long use of air conditioners are the characteristics of hospital buildings. At the same time, general hospitals cover a variety of medical tasks. Therefore, hospital buildings consume more energy[1].

Energy consumption of air conditioning system is one of the important components in the total energy consumption of hospital buildings[2], accounting for about half. According to relevant research, the energy consumption of air conditioning system in hospital buildings is about twice that of the air conditioning system in public buildings[3].

Hu Yangqi et al.[4] found that the energy consumption index of 11 third-class and First-class hospitals in Shanghai was all above 200kWh/m^2•a. Chen Shan [5] conducted an investigation on the medical buildings in Xi 'an and concluded that the energy consumption of the hostipal in this area was 200.1kWh/m^2•a, and the energy consumption of the air conditioning system accounted for 60% of the total energy consumption of the hospital.

In general, air conditioning systems control parameters such as temperature, humidity and pressure. However, the clean operation department has a special purpose, which requires the air conditioning system to have strict air supply volume and scientific air distribution. Therefore, the clean air conditioning system has the characteristics of large air flow, high resistance and high energy consumption[6]. In addition, in the operating room, the cooling load of the air conditioning system is about 2~3 times that of

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the general air conditioning system, which leads to high consumption of cold and heat sources. During the design phase, the designer usually chooses the highest level of the design specification to prepare for design operations and device selection. In the course of operation, the actual air supply may have exceeded the standard range of air supply. The above is the reason of high energy consumption of air conditioning system in clean operation department[7].

For this reason, the relevant parameters of the operation department and the construction of the operation department are specially stipulated in our country. In 2002 and 2013, two Technical Specifications for The Construction of Hospital Clean operation department were issued, both of which defined a clear range of parameters such as temperature and humidity in the operation department. However, these two standards only limit the lower limit of air volume, but do not strictly limit the upper limit of air volume. The designers' excessive pursuit of cleanliness and unreasonable air volume setting in the clean operating room are the causes of energy waste. At the same time, there are no complete energy consumption standards.

Based on the above background, the author conducted investigations on the clean operation department of a hospital in Beijing to study the energy consumption and related characteristics of the clean air conditioning system of the operation department. At the same time, the energy consumption model of the clean operation department was established and verified. On the basis of this model, we set different standard operating conditions and compared and analyzed the energy consumption under the standard operating conditions in China. This paper provides an idea for energy consumption quota of clean operation department in Chinese hospitals.

1. ENERGY CONSUMPTION STATUS AND ENERGY CONSUMPTION ANALYSIS

A hospital in Beijing is a general hospital with a building area of 159609m^2 and its main energy consumption is electricity, water, gas and central heating. In 2018, water and electricity costs in this hospital reached 18 million, accounting for more than 90 percent of total energy costs.

The hospital's energy bills were obtained through the actual investigation of the hospital's energy consumption management platform. Combined with the itemized statistics in the energy bills, the energy consumption of the medical technology complex building of the hospital was calculated. The results show that in 2018, the annual power consumption of the hospital complex building was 8.18 million kWh and that of the HVAC system was 3.87 million kWh, accounting for about 47% of the annual energy consumption.

The energy consumption of the clean operation department area on the fifth floor of the building was investigated. Combined with its energy bill, the investigation into the hospital's energy bills found that the HVAC system in the clean operation department consumed 830,000 kWh in 2018. Annual energy consumption per unit square meter reaches 546kWh. According to the investigation, the cooling source of the clean operation department adopts the cooling mechanism, and the heat source adopts municipal hot water. Therefore, the energy consumption of the air conditioning system of the hospital is mainly electric energy and municipal hot water. This research only studies the electric energy consumption of the HVAC system in the clean operating room. Therefore, it does not include the equivalent power consumption of other energy sources such as municipal hot water. The energy statistical results were divided month by month to

obtain the monthly energy consumption breakdown results of the clean operation part, as shown in Fig 1.

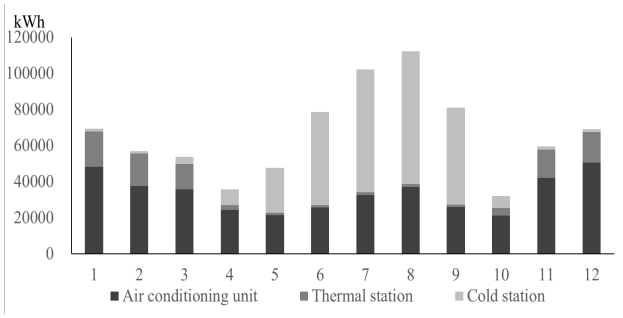

Fig.1 Monthly power consumption chart of air-conditioning unit

It can be seen from Fig 2 that the HVAC system of the operation department has the highest power consumption in summer and the lowest power consumption in transition season. The energy consumption of the HVAC system in the operation department is divided into three parts. The first part is the cooling source part. The second part is the heat source. This hospital uses municipal hot water as the heat source, equipped with a heat station. In this study, the energy consumption only counted the electricity consumption and did not convert the municipal hot water consumption into electric energy. The third part is the unit part. Their energy consumption ratio is shown in Fig 2.

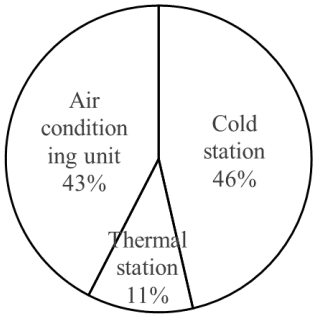

Fig.2 Monthly energy consumption of the operation department

The HVAC system in the operation department is high, and the air conditioning unit takes up a large proportion of the energy consumption, which becomes one of the largest parts of the air conditioning system in the operation department of the hospital. Aiming at the phenomenon of large power consumption of the air conditioning unit in the operating department of the hospital, the power consumption of unit in the last 4 years was statistically analyzed month by month, as shown in Fig 3.

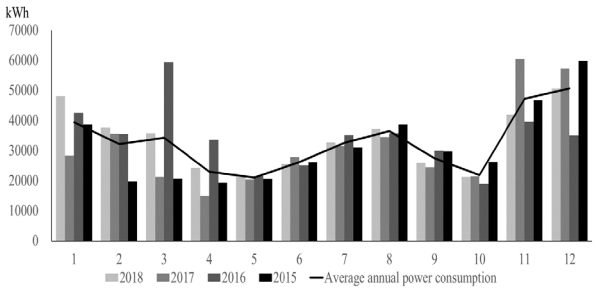

Fig.3 Monthly energy consumption of the operation department

It can be seen from Fig 3 that the energy consumption trend of clean air conditioning units is higher in winter than in summer than in transition season, and the change of outdoor meteorological conditions has a great influence on the energy consumption of clean air conditioning units. Analysis of power consumption trend of air conditioning units :(1) Winter mode of operation increases power consumption. (2) In winter, the unit adopts electric humidification mode leading to high power consumption.

2. ESTABLISH AND VERIFY THE MODEL

The energy consumption simulation software was used to model and verify the model, which provided the basis for the comparison of energy consumption.

2.1 Model building

DesignBuilder software is selected to build the energy consumption model. The hospital's clean operation department is located on the fifth floor, covering an area of about 1,500 square meters. Including five Ⅰ level between the operating room, three Ⅱ level between the operating room, a room Ⅲ operating room and other auxiliary. There are many clean corridors and ancillary rooms in the operation department, and the size of the area is not uniform, but the cleanliness level and the relevant indoor parameters do not differ much. In order to unify the variables and make the study more targeted, the model of clean operation department was simplified and the auxiliary room was combined into one area for study.

2.2 Model verification method

The common verification method of energy consumption simulation model is to compare the actual energy consumption value with the simulated value. The reliability of hourly data verification is the highest. However, it is very difficult to obtain the actual hourly energy consumption when verifying. Therefore, monthly energy consumption and annual energy consumption, which are more easily available, are usually selected as the verification basis. Monthly deviation ($EER_{m,i}$), annual deviation (EER_y) and coefficient of change of standard deviation δ_m[8-10]are obtained by comparing the actual monthly power consumption with the simulated monthly energy consumption value. The calculation formulas are shown in (1)~(5).

$$EER_{m,i} = \frac{M_{ture,i} - M_{cacl,i}}{M_{ture,i}} \times 100\% \quad (1)$$

$$EER_y = \frac{\sum_{i=1}^{12} EER_{m,i}}{12} \quad (2)$$

$$\delta_m = \frac{RMSE}{\overline{M_{ture}}} \quad (3)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{12} (M_{ture,i} - M_{cacl,i})^2}{12}} \quad (4)$$

$$\overline{M_{ture}} = \frac{\sum_{i=1}^{12} M_{ture,i}}{12} \quad (5)$$

In the formula：$M_{ture,i}$ —— The actual value of energy consumption in month i(1≤i≤12)；

$M_{cacl,i}$ —— Simulated calculation value of energy consumption in month i;

$RMSE$ —— Mean square deviation of monthly energy consumption;

$\overline{M_{ture}}$ —— The average of actual monthly energy consumption.

By comparing the calculated index value with the corresponding value in Table 1[11], if it conforms to the deviation range in the table, it can be considered that the model has high reliability and can reflect the actual energy consumption of the building.

Table 1 Range of acceptable simulation deviation index

Acceptable simulation deviation（%）			
Index	M&V	ASHRAE	IPMVP
$EER_{m,i}$	15	5	20
EER_y	10	/	/
δ_m	10	15	5

2.3 The validation results of the model

Combined with the data from the investigation department and the operation and maintenance department, Energy consumption statistics were carried out for the clean operation department on the fifth floor, and the energy consumption without separate measurement was scientifically divided and calculated. Combined with the above methods, the

actual operating power consumption of the air conditioning system in the operation department in 2018 is analyzed and sorted out. The simulation results are compared and analyzed and verified monthly. The results are shown in Fig 4.

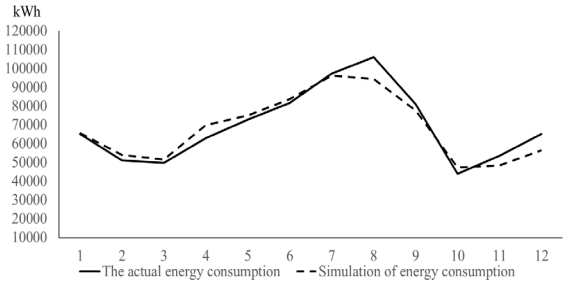

Fig 4 Comparison result of monthly energy consumption

Although there is a certain deviation, the simulation results meet the requirements related to the error rate, and can basically reflect the real energy consumption situation. It is considered that the model and its output results are more reliable.

3. ENERGY CONSUMPTION ANALYSIS OF OPERATION DEPARTMENT UNDER DIFFERENT DESIGN STANDARDS IN CHINA

In order to study the energy consumption status of the operation department and the energy consumption of Chinese standard. Using the surgical department model, the old Chinese GB50333-2002 standard [12] and the standard GB50333-2013 standard [13] were selected to simulate the setting conditions.

Working condition 1 and 2 were respectively set according to the upper and lower limits of air volume in all levels of clean areas stipulated in the old National standard of China. Since the new standard only specifies the lower limit of air volume in all levels of clean areas, only the lower limit of air volume is set as the third working condition. Condition as shown in table 2.

Table 2 Working condition design

name	room type	supply air requirement	fresh air requirement
Condition 1	Level l operating room	Surface wind speed 0.25m/s	6ACH
	Level Ⅱ operating room	30ACH	6ACH
	Level Ⅲ operating room	18ACH	4ACH
	Auxiliary room	8ACH	3ACH
Condition 2	Level l operating room	Surface wind speed 0.3m/s	6ACH
	Level Ⅱ operating room	36ACH	6ACH
	Level Ⅲ operating room	22ACH	4ACH
	Auxiliary room	10ACH	3ACH
Condition 3	Level l operating room	Surface wind speed 0.2m/s	15m³/h·m²
	Level Ⅱ operating room	24ACH	15m³/h·m²
	Level Ⅲ operating room	18ACH	15m³/h·m²
	Auxiliary room	8ACH	2ACH

The energy consumption results of the clean operation unit under the following operating conditions were simulated and analyzed with the current energy consumption of the clean operation unit. The results are shown in Fig 5.

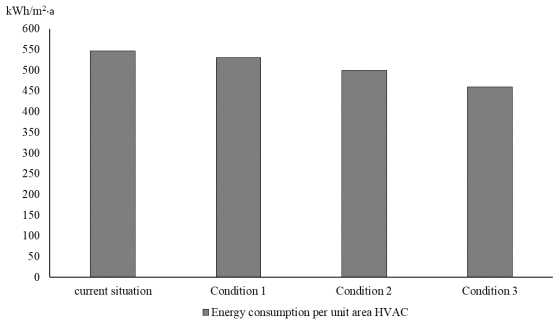

Fig 5 comparison of energy consumption

FIG. 5 shows that the energy consumption in working condition 3 is low, lower than that in working condition 1 and 2, and the current energy consumption of the operation part. This indicates that the new Chinese national standard not only ensures the cleanliness of the clean operation department but also reduces some energy consumption. The current energy consumption of the air conditioning system in

the operating department of the hospital is about 550kWh/ year ·m^2, higher than all working conditions, reaching the upper limit required by the old version of the standard in China and exceeding the new standard in China.

Since the operation department was built before the new Chinese standard was issued in 2013, it was designed and constructed according to the old standard, and the excessive air volume caused the operation department to exceed the upper limit recommended by the standard, thus causing unnecessary waste of energy. Taking the current energy consumption of the operation department as a reference, operating under the upper and lower limits of the old national standard air volume can save energy of 3% and 9% respectively. In accordance with working condition 3, the lower limit of air volume set by the new national standard, the energy consumption level is about 460kWh/ year ·m^2, which can save 16% compared with the current situation of the operation department, and the annual electricity saving can reach about 135,000 kWh. In the same lower limit condition, the new national standard can reduce energy consumption by 10% compared with the old one.

4. DISCUSSION

Combined with the actual situation in China, the majority of hospitals and their operating departments were built earlier and followed the old national standards at that time. In recent years, with the continuous upgrading of the medical system, the scale of the newly-built and rebuilt surgery department has been increasing, and a large number of surgery departments need to be upgraded, so there is a lot of space for energy saving. However, due to the lack of energy consumption quota, there is no clear standard for the determination of energy saving standard. Operating rooms in China are complex. At the same time, most hospitals do not set a separate measurement of energy consumption for the operation department, so there is no way to conduct research through the traditional method of investigation.

This verified energy consumption simulation method provides a quantifiable benchmark model of energy consumption. By modifying relevant parameters of the model (weather, service time, etc.), the standard value of energy consumption limit of the clean operation department is made possible. The quota combined with the current situation of energy consumption and the energy consumption under the national standard operating conditions can provide ideas for the energy consumption quota of air conditioning system in the department of clean surgery in China.

5. CONCLUSIONS

(1) In 2018, the energy consumption of HVAC in the operating department of the hospital was 830,000 kWh, with an annual power consumption of 546kWh per square meter. The energy consumption of air conditioning system in clean operation department is obviously higher than other common air conditioning system. Different from the common air-conditioning system, the energy consumption of the air-conditioning unit in the clean operation department accounts for nearly half, which is the most power consumption part of the whole HVAC system. The power consumption of air-conditioning unit is higher in winter than in summer. And the air conditioning unit using the electric humidification mode has higher power consumption.

(2) The clean air conditioning system of the operation department has a high energy consumption, mainly because the air volume of the air

conditioning system is set too high, which causes a certain amount of energy waste. Taking the clean operation department as an example, the new Chinese standard can save 16% of energy compared with the current energy consumption, under this circumstance, the annual power consumption of the clean operation department is 460kWh per square meter.

(3) The new standard can save 10% energy compared with the old standard if the low limit of air supply is set. There is a large space for energy saving in the clean air conditioning system of the operation department in China.

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