C. Wang et al. (Eds.)

doi:10.3233/ATDE230368

Research on Energy Saving and Capacity Increase Reform of Ice Storage System in Museum

Wenyuan WANG[1]
China Science and Technology Museum, Beijing 100012, China

Abstract. Ice storage is one of the important green energy-saving technologies in the air conditioning industry. Based on the increasing cooling load demand of the exhibition hall and the energy-saving demand, this paper studies how to promote green and sustainable development from the perspective of energy-saving and capacity increase reform of the ice storage system in the museum. Taking China Science and Technology Museum as an example, after the reform, the electricity saving rate of theoretical calculation and actual operation in July is 31.26% and 31.8% respectively. The annual energy saving rate, annual electricity saving rate, and annual cooling capacity increase rate are 45%, 33%, and 28% respectively. The capacity increase reform is very effective in green energy saving and sustainable development. Finally, the energy-saving transformation strategy of the ice storage system in the museum is further discussed from the perspective of different cold storage technologies and the energy-saving of other components of the ice storage system.

Keywords. Ice storage, museum, energy saving, capacity increase reform

1. Introduction

Ice storage is a technology that can effectively improve energy efficiency and optimize resource allocation [1]. Ice storage technology is successfully developed and applied in the United States at the beginning of the last century, and China introduce this technology around the 1990s. Ice storage is widely used in museums. However, some museums that have already installed ice storage equipment are facing the practical demand of upgrading or increasing the capacity of the equipment. For example, China News Network once reported that the number of people in some museums surged during the summer, greatly exceeding the daily average optimal carrying capacity. On the one hand, the museum has become a “summer resort”, on the other hand, the cold load of the exhibition hall exceeds expectations. The theme of International Museum Day in 2023 is “Museums, Sustainability and Wellbeing”. The refrigeration system of the museum is promising in terms of green, energy saving and sustainable development.

This paper discusses the energy saving and capacity increase reform of the ice storage system in the museum, based on the increasing demand for cooling load in the exhibition hall.

[1] Corresponding Author, Wenyuan WANG, China Science and Technology Museum, Beijing 100012, China; Email: 2158570657@qq.com.

2. The Necessity of Research

2.1. Characteristics of Ice Storage System

Ice storage technology can have excellent economic benefits for the museum and the local power system. Kang [2] pointed out that buildings were better suited to use ice storage technology, when the area supported peak and valley prices, and the cooling load was large or concentrated during the day. It can not only save bills, but also shift peaks and fill valleys. The comparison between ice storage system and traditional central air conditioning refrigeration is shown in Table 1.

Table 1. Comparison between the ice storage system and traditional central air conditioning.

Item	Traditional central air conditioning	Ice storage system
Initial investment	Smaller	Higher
Electricity bill	More	Less
Impact on power system stability	Unfavorable	Favorable

2.2. Green Energy Saving and Ice Storage Application in Museum

2.2.1. Feasibility of Ice Storage Application in Museum

There are significant differences between museums and ordinary buildings in terms of indoor air conditioning cooling load. The characteristics are as follows:

- The museum's cold load is uneven throughout the day and hour. For example, the night cold load of the air conditioning system in Jiangxi Natural Science Museum is only about 20% of that in the daytime [3]. The design daily peak load of the air conditioning system in the National Museum of China is 5616RT, and the valley value is only 520RT [4].
- The museum has a large area, mostly for centralized cooling, and there is also space for ice troughs. For example, the minimum exhibition hall area of the China Science and Technology Museum is 626 m^2.
- The museum needs a stable cooling system. In order to avoid the temperature rise in the exhibition hall caused by the accidental shutdown of the refrigeration unit or power outage, which affects the visitors' visiting experience.

2.2.2. Demand for Capacity Increase Reform of Ice Storage System in Museum

The heat dissipation of tourists' bodies is one of the main cold loads of museum air conditioning. In recent years, the number of museum visitors has generally increased, except during the period affected by the COVID-19 epidemic. The book "The museum experience revisited" mentioned that in the last 25 years of the 20th century, the number of museum visitors increased exponentially [5]. Another example, the number of visitors to the China Science and Technology Museum which had 2 million visitors in 2009, is reached 3.89 million in 2019, almost doubling the number. At the same time, some museums that have installed ice storage system also face problems such as equipment aging and cooling efficiency decreasing year by year.

Therefore, it is necessary to keep the ice storage system in the museum running efficiently and to upgrade and expand the capacity when necessary.

3. An Example

3.1. Project Overview

The exhibition hall of the China Science and Technology Museum adopts an ice storage air conditioning system for cooling. The cold source adopts three dual-condition refrigeration units. The air conditioning power of each unit is 538 kW, and the ice-making power is 448 kW. As the number of visitors increases year by year, and as the age of the refrigeration unit increases, the efficiency of the refrigeration unit decreases. The ice storage system has insufficient ice production at night, which leads to the need to open the refrigeration unit for a period of time during the day in July and August to replenish cooling capacity.

In order to meet the demand for upgrading the cooling capacity, a new dual-condition refrigeration unit with ice-making power of 529.3 kW was added in 2016.

3.2. Theoretical Calculation of Electricity Saving Rate

The energy consumption in July 2015 and July 2017 is used as an example to calculate the theoretical values before and after the system capacity reform. Before the reform, the ice storage system made ice at night and melted ice during the day in July. At the same time, during the high load time (13:00-15:00), three additional refrigeration units were turned on to make up for the lack of cooling capacity. After the reform, the nighttime ice production capacity basically meets the daytime demand, without the need to turn on additional refrigeration units. The museum is closed every Monday, so the ice storage system actually operated for 26 days in July. It is assumed that the ice storage system and the air conditioning system operate at rated power, without considering the effects of outdoor temperature and visitor disturbances.

The energy consumption (unit: kW), the electricity bill (unit: yuan), and the electricity saving rate are expressed by *E, C* and *ε* respectively. Before and after the reform, the energy consumption is expressed by *E1* and *E2* respectively, the electricity bill is expressed by *C1* and *C2* respectively.

Before the reform, the daily energy consumption and electricity bill of the ice storage system consisted of three parts *(E11(C11), E12(C12), and E13(C12))*, as follows:

- Making ice at night (8 hours).
- Melting ice during the day (9 hours).
- Running refrigeration units during the day (2 hours).

After the reform, the ice storage system can store enough ice to meet daytime use, the daily energy consumption and electricity bill of the ice storage system consisted of two parts *(E21(C21), E22(C22))*, as follows:

- Making ice at night (8 hours).
- Melting ice during the day (9 hours).

The energy consumption and electricity bill are shown in Table 2.

Table 2. Energy consumption and electricity bill before and after the reform.

E11	*E12*	*E13*	*E21*	*E22*	*C11*	*C12*	*C13*	*C21*	*C22*
15432	4455	2424	19666.4	4455	4629.6	5271.75	6350.88	5899.92	5271.75

According to Table 2, the value of $C1$ is 16252.23, the value of $C2$ is 11171.67, and the value of ε is calculated as follows:

$$\varepsilon=(C1-C2)/C1=31.26\% \quad (1)$$

3.3. Comparison of Actual Values before and after the Reform

3.3.1. Electricity Consumption, Electricity Bill, Cooling Capacity and Number of Visitors in July

Figure 1 shows the comparison of actual values between July 2015 and July 2017. It can be seen that the exhibition hall has lower electricity consumption, lower electricity bill, higher cooling capacity and a higher number of visitors in July 2017 compared with the same period in 2015. Compared with July 2015, July 2017 saved 116000 yuan in electricity bill, with a saving rate of 31.8%.

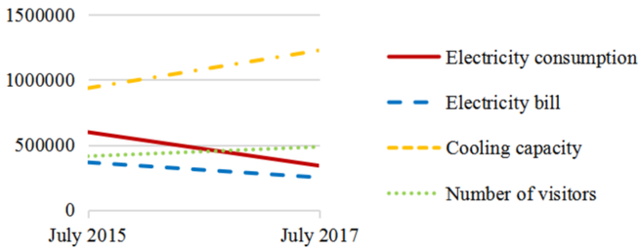

Figure 1. Comparison of actual values between July 2015 and July 2017.

3.3.2. Comparison of Annual Electricity Consumption, Electricity Bill, Cooling Capacity and Number of Visitors

Figure 2 shows the changes in actual values from 2013 to 2018. The data for 2016 is not included. The electricity consumption and electricity bill remained basically stable, and the cooling capacity decreased slightly year by year from 2013 to 2015, indicating that the efficiency of the ice storage system is decreasing. Compared with 2015, in 2017 the actual annual electricity consumption has decreased by 920000 kWh, with an annual electricity saving rate of 45%, the annual electricity bill has decreased by 390000 yuan, with an annual electricity saving rate of 33%, the annual cooling capacity has increased by 850000 kW, with an annual increase rate of 28%.

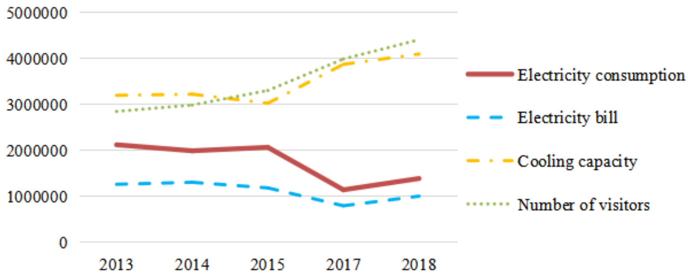

Figure 2. Changes in actual values from 2013 to 2018.

3.4. Analysis of Electricity Saving Rate

3.4.1. Theoretical and Actual Energy Savings Rates in July

In July 2017, the theoretical calculation of the electricity saving rate is 31.26%, and the actual operation is 31.8%. The actual operation and theoretical calculation are similar, indicating that the ice storage system has significantly saved electricity bill after the reform. The main reason is that after adding a new refrigeration unit, by increasing the amount of ice storage at night, there is no need to start the refrigeration unit during the day, thus saving electricity bill.

3.4.2. Electricity Saving Rate in July and Annual Electricity Saving Rate

The actual annual electricity saving rate (33%) in 2017 was slightly higher than the electricity saving rate in July. Before the renovation, the COP value of the three dual-condition centrifugal refrigeration units is 5.1. But due to the use of many years, the actual operating COP is less than 5.1, the efficiency is low. The COP value of the new refrigeration unit is 5.77. In the actual use process in 2017, the new unit is used more, and old units with low COP are used less under the same working conditions.

4. Discussion

4.1. Selection of Different Cold Storage Technologies

In this study, the efficiency and cooling capacity are improved, and the electricity consumption and electricity bill are reduced, by increasing the capacity of the original ice storage system. Other cold storage technologies, such as heat pipe cold storage, water cold storage, etc., can also make full use of valley electricity tariff refrigeration and reduce bills. Fang [6] compared the cold storage system using heat pipe and ice, and found that the efficiency of the cold storage system using heat pipe was 9.55 % higher than that using ice. Shu [7] pointed out that both water storage and ice storage had good performance, but they were suitable for different working conditions, water storage did not need to add chillers below zero temperature. Taking an example of the application of water storage technology in museums, such as the China Arts and Crafts Museum [8]. It was completed and opened in 2022, with a cold storage pool area of about 530 m^2 and a storage capacity of about 2650 m^3. After practical testing, the energy-saving effect was good.

4.2. Energy Saving in Other Components of Ice Storage System

In this study, only a single energy-saving method using an ice storage system to increase capacity is used. If combined with other energy-saving components, the energy-saving effect is better. For example, Liang [9] proposed a new type of air conditioning system that combined an ice storage system with capillary radiation technology. It could not only cut the peak and fill the valley, but also control the temperature and humidity independently. In addition to the energy-saving transformation at the end of the ice storage system, the use of more efficient graphene materials, nano-thermal conductive composite materials and other coil pipes is also a feasible solution for green energy-saving transformation. For example, the office building of Pan’an County power supply company was officially put into operation in 2023, and the ice storage device adopted graphene composite material. Compared with the traditional steel pipe material, it had the characteristics of high thermal conductivity and a large heat transfer area.

5. Conclusion

This article analyzes the comparison between ice storage and traditional cooling mode, as well as the potential for application in museums. Through theoretical analysis and practical examples, the application of ice storage technology in energy saving of museum air conditioning system is discussed. The main conclusions are as follows:

- The cooling load of the museum has a large gap between day and night, which is suitable for the use of ice storage technology. However, it also faces the pressure of system upgrading, such as increasing cooling load demand and decreasing equipment efficiency year by year.
- The theoretical calculation and actual operation electricity saving rates in July 2017 are 31.26% and 31.8% respectively, significantly saving electricity bill.
- The energy saving rate, electricity saving rate and cooling capacity increase rate in 2017 are 45%, 33% and 28% respectively compared with those in 2015.
- The feasibility of energy saving of different cold storage technologies and other components of ice storage system in energy saving reform is discussed.

Due to the limited practical experience and information, it is also necessary to consider the impact of outdoor temperature and visitor disturbance in research.

References

[1] Zhang WY, Zhang BH, Cheng X. Application analysis of ice storage district cooling system technology. Building Energy Saving. 2021;49(03):109-112.
[2] Kang Z, Wang R, Zhou X, et al. Research status of ice-storage air-conditioning system. Procedia Engineering. 2017;205:1741-1747.
[3] Wu T. Technical and economic analysis of cold and heat source schemes of air conditioning system in Jiangxi Museum. Cooling Air Conditioning and Electric Machinery. 2011;32(04):38-41+45.
[4] Guo YR. On Analysis of ice storage cooling air-conditioner scheme in projects of National Museum of China. Shanxi Architecture, 2011;37 (21):96-98.
[5] Falk J H, Dierking L D. The Museum Experience Revisited. 2013.
[6] Fang G, Liu X. Exergy analysis of ice storage air-conditioning system with heat pipe during charging period. Energy for Sustainable Development. 2010;14(2):149-153.
[7] Shu JX. Chilled energy storage for air-conditioning system of buildings. Applied Mechanics & Materials. 2014;496-500:1020-1023.
[8] Cao Y, Guo ZJ, Han FF. Air conditioning design of China Arts and Crafts Museum·China intangible cultural heritage museum. Building Science. 2022;38(05):69-76.
[9] Liang K, Ren X, Ruan C, et al. Operation modes and energy analysis of a new ice-storage air-conditioning system. Open Electrical & Electronic Engineering Journal. 2015;9(1):7-14.