Research on Energy Consumption Evaluation Method and Energy Saving Operation Technology of Cold Storage

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Abstract- There is not yet a recognized unified energy consumption assessment and grading method on cold storage. It is not conducive to cold storage operation energy-saving management. By establishing the heat balance model of the cold storage, the energy consumption composition of the cold storage is analyzed, and then the causal diagram analysis method is used to determine the influencing factors of the energy consumption of the cold storage, and the quantitative indicators to measure the energy consumption of the cold storage are proposed. Based on the classification of energy consumption assessment methods for cold storage, five typical energy consumption assessment methods for cold storage are compared and analyzed from five aspects of quantification, evaluation index, energy efficiency level, application scope and shortcomings. It is found that to establish an energy efficiency level identification evaluation standard for cold storage recognized by the public, two conditions must be met: the appropriate energy consumption assessment method considering the differentiation of cold storage; establishment of a large database of cold storage energy consumption information. Accordingly, the ways and measures for energy saving of cold storage are proposed.

1. Introduction
The cold storage belongs to high energy consumption building. According to the preliminary investigation of some cold storage, the electricity cost is generally too high, accounting for an average of 44% of the total operating cost; high temperature market cold storage’s loss rate is almost 100%; the goods stored by market customers are generally short-term goods with short storage life, high temperature, high power consumption and high cost. It is not hard to find that the key problem is the energy consumption of the cold storage which is much higher in China than that of the average level of developed countries. The reasons include the uneven construction of cold storage in China, the variety of related facilities, the lack of professional talents, the imperfect specification and the shortage of professional selection of related facilities, which makes it difficult to evaluate the energy consumption of built cold storage. The energy consumption of cold storage cannot be effectively evaluated, which is not conducive to the realization of energy saving and emission reduction goals in China, and also restricts the smooth development of cold chain service industry. The energy consumption evaluation method can be used to determine the energy consumption level, energy saving potential, energy saving measures and its economy of the existing cold storage. It is an important standard for energy saving measures and schemes, and is of great significance for the energy saving of
cold storage\cite{1}. This paper compares and analyzes several different evaluation methods of cold storage energy consumption proposed by national standards, industry standards and local standards promulgated or drafted in China, and studies their advantages, disadvantages and scope of application.

2. Analysis of influencing factors energy consumption of cold storage

2.1. Energy consumption composition analysis of cold storage

The energy consumption of cold storage refers to all the energy consumed by the cold storage building in the use process, which is mainly composed of the energy consumed by the refrigeration, lighting, elevator, transportation equipment and other systems. The total energy consumption of the cold storage system is the sum of the energy consumption of the refrigeration system of the cold storage system and the direct energy consumption of the electrical components (including lighting, chillers, defrosting, wind curtain, automatic control, auxiliary heating equipment and circulating pumps, etc., which meet the normal operation of the cold storage system. All ancillary equipment used for electricity). Among them, the refrigeration system energy consumption accounts for the majority in the entire cold storage building energy consumption. Therefore, when analyzing and calculating the energy consumption of cold storage, the load of cold storage refrigeration system cannot be simply mixed with the energy consumption of cold storage. Cold storage refrigeration system load is to eliminate heat generated in the cold storage refrigerating capacity; the energy consumption of cold storage is all the power consumed by considering the influence of cold storage, external environment and enclosure structure.

Based on the combined action of evaporator, goods and electrical equipment in cold storage, building envelope and cold storage door, the thermodynamic system model of cold storage is established. The cold storage building is mainly affected by external environment, refrigeration system and other factors. It can be considered to be composed of the heat balance of the enclosure structure and the heat balance of the air in the cold storage\cite{2}, as shown in Fig. 1. The temperature of the cold storage is generally about -25 °C, while the daytime temperature outdoor in summer is generally above 30 °C. In other words, the temperature difference between the two sides of the enclosure structure of the cold storage will be about 60 °C. In addition, the solar radiation heat in the daytime makes the heat load formed by the heat transfer from the wall and ceiling to the cold storage considerable, which is an important part of the heat load in the whole cold storage.

![Fig. 1 The heat balance model of refrigeration storage](image)

Cold storage refrigeration system load generally includes: (a) heat transfer of enclosure structure; (b) heat dissipation of goods stored in the cold storage; (c) cooling of cold storage equipment. The cooling load of refrigeration system can be calculated by Formula (1):
In the above formula, $Q$—the cooling load of cold storage refrigeration system, W; $Q_c$—heat dissipation of goods in cold storage, W; $Q_w$—heat formed by cold storage enclosure structure, W; $Q_e$—heat formed by electrical equipment in cold storage, W; $Q_h$—heat formed by human body in cold storage, W; $Q_g$—heat from opening of cold storage door, W.

2.2. Analysis on influencing factors of cold storage energy consumption

The energy consumption of cold storage is not only related to the characteristics of the cold storage refrigeration unit, but also related to the internal and external environment of the cold storage and its own structure. Under the condition that the characteristics of the refrigeration unit remain unchanged, how to accurately analyze and determine the influencing factors of energy consumption becomes the key to solve the problem of energy consumption evaluation. Fishbone diagram analysis is used to determine the cold storage energy consumption factors, as shown in Fig. 2.

Fig. 2 The factor graph analysis of energy consumption of refrigeration storage

Referring to Fig. 2, the main factors affecting the energy consumption of cold storage include:
(a) Goods in the cold storage: quantity, type and initial temperature;
(b) Cold storage enclosure structure and door: thickness of enclosure and door, material and door heat transfer coefficient, enclosure comprehensive heat transfer coefficient;
(c) Refrigeration system: energy efficiency and load of refrigeration units;
(d) External environment of cold storage: ambient temperature, relative humidity, solar radiation, etc.;
(e) Cold storage electrical equipment: the power, work efficiency, heat transfer coefficient of the mechanical and electrical equipment required for the operation of the cold storage.

2.3. Quantitative indicators for measuring energy consumption of cold storage

The energy consumption of cold storage is usually measured by the energy consumption of cold storage. There are two kinds of cold storage power consumption index: absolute index and relative index. The absolute power consumption index of a cold storage refers to the sum of electricity consumed by a cold storage within a given time, such as daily (monthly, seasonal, annual) power consumption (KW·h). The absolute power consumption index of a cold storage refers to the average power consumption per unit storage capacity (unit weight of goods) per unit time of a cold storage, such as the power consumption per cubic meter day (month, season and year) (KW·h/m³·d) and per ton day (month, season and year) (KW·h/t·d). It is obviously not suitable to use absolute index to compare
the energy consumption level between cold storage. The power consumption of cold storage is certainly different due to the difference in size, and the absolute index cannot be used to evaluate the energy consumption level. Therefore, quantitative indicators to measure the level of energy consumption of cold storage and quantitative assessment of energy consumption of cold storage generally use relative indicators: daily or annual power consumption per cubic meter storage capacity (KW·h/m³·d, KW·h/m³·y).

3. Comparative analysis of energy consumption assessment methods for cold storage
At present, many kinds of cold storage energy consumption evaluation methods have been developed at home and abroad. These methods have their own merits: some are very similar, some are very different, some are qualitative, some are quantitative, and have not become widely accepted standards. This paper will compare and analyze some typical energy consumption evaluation methods at home and abroad, and propose an effective way to take energy saving measures for cold storage operation.

3.1. Classification of energy consumption assessment methods for cold storage
According to whether the evaluation index can be calculated quantitatively, the evaluation method of cold storage energy consumption is divided into quantitative method and qualitative method. Quantitative methods of cold storage energy consumption assessment mainly include “CE-E” plan, calculation method of energy consumption coefficient evaluation index of cold storage system, unit power consumption limit and calculation method of Zhejiang cold storage. The qualitative methods for energy consumption assessment of cold storage mainly include the self-assessment checklist method for energy efficiency status of refrigeration system and the evaluation index method for energy efficiency facilities of food cold storage.

According to whether the energy efficiency (energy consumption) identification grade standard is established, the cold storage energy consumption evaluation method is divided into two categories: energy efficiency grade identification method and energy efficiency qualification judgment method. The “CE-E” plan and the evaluation index method of energy efficiency facilities of food cold storage establish the energy efficiency grade identification, which belongs to the energy efficiency grade identification method. The calculation method of energy consumption coefficient evaluation index of cold storage system, the unit power consumption limit and calculation method of Zhejiang cold storage, and the self-examination and evaluation list method of energy efficiency state of refrigeration system do not provide energy efficiency grade identification, so it belongs to the energy efficiency qualification judgment method.

3.2. Typical energy consumption evaluation method of cold storage
(1) The “ICE-E” plan. The “CE-E” plan jointly carried out by eight European units counted 295 cold storage information in 21 countries, determined the average energy consumption, and established energy consumption identification based on Simple and Simulation methods. The “ICE-E” uses the method of collecting information online. The main collection parameters include the set temperature in the storage, the area in the library, the volume in the library, the average annual quality of incoming and outgoing goods, and the annual power consumption. The “ICE-E” divides the cold storage into cold, frozen and mixed storage depending on the temperature in the storage. Using the steady-state simulation method, EVANS J.A. et al. developed a steady-state model for predicting the energy consumption of cold storage\cite{3}, using the average annual energy consumption per cubic meter of storage capacity (KW·h/m³·y) as the evaluation index, and based on the survey data of “ICE-E”, they established a seven-level energy consumption label from A to G, where A represents the highest energy efficiency. The deficiency of this method is that the steady-state model cannot be used to simulate the hourly energy consumption of the whole year, which makes the prediction value of the energy consumption of the cold storage in non-annual operation relatively large, and does not consider the influence of seasonal factors on energy consumption, so the energy consumption prediction is not
accurate. Without considering the influence of climate zones on energy consumption, the comparison between cold storages in different climate zones is not objective[1].

(2) Calculation method of energy consumption coefficient evaluation index of cold storage system. This is a calculation method of energy consumption coefficient evaluation index of cold storage system provided in Reference[4]. The method includes the following steps: 1) Calculate the mechanical load \( Q_j \) when the refrigeration compressor is selected for the cold storage; 2) Determine the refrigeration unit energy efficiency coefficient \( \text{COP} \); 3) Calculate the cooling power consumption \( \text{REC} \); 4) Calculate the direct power consumption \( \text{DEC} \); 5) Calculate the total energy consumption of cold storage system \( \text{TEC} \); 6) Calculate the energy consumption coefficient \( \varepsilon \) of the cold storage system[5], that is, the average power consumption per cubic meter of storage capacity per day (kW·h/m\(^3\)·24h)[6]. This method can judge whether the cold storage energy consumption is qualified by comparing the calculated value and the measured value of the cold storage system energy consumption coefficient.

(3) The unit power consumption limit and calculation method of Zhejiang cryogenic cold storage. This method is provided by the local standard of Zhejiang Province’s Unit Power Consumption Limit and Calculation Method of Low-temperature Cold Storage (DB 33/763-2009). It is suitable for the calculation and evaluation of the power consumption of the refrigeration system of low-temperature cold storage with nominal volume of 50m\(^3\) and above. It is not suitable for the cold storage room (high temperature storage), the air conditioning storage, the cave cold storage and the stone arch clay cold storage. It is used for the assessment and management of the power consumption index of low-temperature cold storage[7]. The standard stipulates the unit power consumption limit of frozen storage (kW·h/m\(^3\)·30d) and the unit power consumption limit of frozen processing (kW·h/t, kW·h/t), and provides the calculation method of unit power consumption of low-temperature cold storage.

(4) Refrigeration system energy efficiency status self-assessment checklist method. This method is provided by the national standard Energy-saving Operation Regulations of Refrigeration System Part 1: Ammonia Refrigeration System (GB /T 33841.1-2017) Appendix A Self-inspection and Evaluation List of Energy Efficiency Status of Refrigeration System. The design of typical food processing refrigeration system mainly includes industrial ammonia refrigeration system and equipment operation adjustment, and does not include all factors to improve efficiency. The self-checking evaluation list sets weights (scores) for each problem according to the impact on total efficiency and the impact on operating costs[8]. Accordingly, the efficiency of the refrigeration system or the potential for efficiency improvement is evaluated. The method provides scoring standards and grading standards. For systems with an evaluation score of less than 70, the operation mode should be modified or improved through this standard and list. Even if the score is excellent, there are some options to reduce energy costs. The only way to keep the refrigeration system in optimal condition is regular maintenance and careful operation adjustment[7].

(5) Evaluation index method for energy efficiency facilities of food cold storage. This method is provided by the China Federation of Logistics and Procurement Logistics Industry Standard Evaluation Index of Energy Efficiency Facilities for Food Refrigerators (draft for comments), which is applicable to cold storages with nominal volume above 5000m\(^3\) and is not applicable to cave cold storages and air conditioning storages[9]. The standard adopts the scoring method to design the evaluation index and score calculation method of the energy efficiency facility level of the cold storage under the premise of the cold storage temperature reaching the standard, and the criterion of determining the energy efficiency facility level of the cold storage by taking the comprehensive score E value[10].

3.3. Comparative analysis of cold storage energy consumption evaluation methods
Through comparative analysis, we can find that these five kinds of cold storage energy consumption evaluation methods have certain limitations. Thus, the public energy efficiency grade identification evaluation criteria are convincing and is hardly recognized by the public. The “ICE-E” plan uses annual energy consumption per cubic meter (KW·h/m\(^3\)·y) to evaluate the energy consumption of cold storage, which cannot accurately predict the energy consumption of cold storage in non-annual
operation. The calculation method of energy consumption coefficient evaluation index of cold storage system can better predict the average power consumption per cubic meter of cold storage per day (kW·h/m³·24h). However, due to the lack of measured data of cold storage, it is impossible to determine the energy efficiency level standard, and only the energy consumption qualification can be judged. The other two qualitative evaluation methods use subjective scoring method for grading evaluation, with too much subjectivity, thus energy efficiency grade evaluation results cannot be convincing.

There are great differences in the refrigeration system, building structure, area volume, operation mode and personnel operation of cold storage. It is very difficult to establish a set of energy consumption assessment methods and energy efficiency grade standards suitable for all cold storages. In addition to establishing an appropriate quantitative index calculation model of cold storage energy consumption, it is also necessary to establish a complete and systematic investigation database of cold storage building energy consumption through long-term efforts. Comprehensive information survey including the setting temperature in the cold storage, the volume of the area in the cold storage, the average quality of goods in and out of the month, the annual power consumption of the month, the material and size of the enclosure structure, the building age of the cold storage, the operation mode of the refrigeration system, the operation of the personnel in the cold storage, and the operation of other energy consumption equipment (lighting, elevator, transportation equipment, etc.), and ensure that the information source is reliable and the information screening is reasonable.

4. Energy saving technology and measures for cold storage operation
There may be a waste of energy in every part of the cold storage. If reasonable measures are not taken, the waste of energy is considerable. These are a lot of ways and measures for energy saving of cold storage according to several main links affecting the energy consumption of cold storage: **reducing heat load of cold storage, improving the efficiency of refrigeration system, reasonable use of night running time, using compressor waste heat, reducing the unit heat flow of the cold storage enclosure structure, etc.**

5. Conclusion
It is of great economic and practical significance to study the energy consumption evaluation method of cold storage and establish the energy efficiency grade identification system for guiding the design, construction and operation of cold storage. According to the results of comparative analysis of the energy consumption evaluation methods of cold storage, it is very difficult to establish a universally recognized and widely accepted energy efficiency grade identification system of cold storage because of the huge differences in the configuration, size, operating conditions and methods, working environment and region of the refrigeration system. In addition to the research and design of an appropriate energy consumption evaluation method that can take these huge differences into account, a large database on the energy consumption information of cold storage must be established as the data support conditions for the classification of the energy efficiency grade of cold storage using this evaluation method. We hope this work can provide some useful inspiration.

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