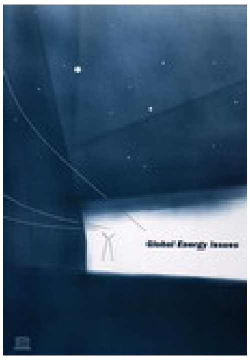

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Energy efficiency evaluation method of refrigeration and air conditioning in intelligent buildings based on improved entropy value method

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Energy efficiency evaluation method of refrigeration and air conditioning in intelligent buildings based on improved entropy value method

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Abstract: In order to improve the accuracy and precision of the evaluation of cold source energy efficiency, this paper proposes an evaluation method of cold source energy efficiency of refrigeration and air conditioning in intelligent buildings based on the improved entropy method. On the basis of analysing the energy efficiency ratio composition of refrigeration and air conditioning system, the calculation process of energy efficiency ratio is refined by using refrigeration energy efficiency transport function. Then the AHM improved entropy method was used to optimise the weight ratio process, and the efficient and accurate evaluation of the cooling source energy efficiency of refrigeration and air conditioning was completed by adjusting the weight ratio. The experimental results show that the average evaluation accuracy of the proposed method is 95.9% and the average evaluation accuracy is 96.3%, which proves that the proposed method achieves the design expectation.

Keywords: improved entropy method; operational energy efficiency ratio; intelligent building; refrigeration and air conditioning; evaluation of energy efficiency of cold source.

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1 Introduction

With the improvement of social quality and people's living standard, people's requirements for living environment are also constantly improved (Ng et al., 2019; Ndukaife and Nnanna, 2019; Xue et al., 2020). In the intelligent building, the air conditioning system is an important part of it, which can realise the heating and cooling functions, and meet the needs of people for the regulation of the temperature environment. For the refrigeration and air conditioning of intelligent building, the higher its refrigeration efficiency, the more it can complete the refrigeration task in the case of low energy consumption. To evaluate the energy efficiency of the cold source and optimise the working process of refrigeration and air conditioning according to the evaluation results is more beneficial to improve its working efficiency (Zhang et al., 2020; Bravo et al., 2020). Therefore, it is of great practical significance to design an effective evaluation method of air conditioning cold source energy efficiency.

In Sheng et al. (2019), a method for energy efficiency evaluation of air conditioning system is designed. After establishing the energy efficiency evaluation method of air conditioning system from whole to part, the energy efficiency reference limit of each subsystem is given, and the energy efficiency evaluation is completed according to the limit. However, it is found that the evaluation accuracy of this method is low in practical application. Zhao et al. (2020) designed the daily evaluation index of air conditioning system energy consumption based on data-driven, and then analysed the historical data of building daily air conditioning system energy consumption by using K-means clustering algorithm, constructed a comparison database, and completed the evaluation of air conditioning energy efficiency by using simulation software. However, the evaluation accuracy of this method is found to be low in practical application (Tang, 2020). Based on the monitoring data of air-conditioning, the energy efficiency coefficient EER-SYS of the air-conditioning cold source system was calculated, and the intelligent algorithm was used to obtain the coefficient characteristics. Then, the energy efficiency coefficient was measured to complete the evaluation of the energy efficiency of the air-conditioning cold source. In the practical application, it is found that the calculation process of this method is more complex, and it has higher requirements for the application environment, so it lacks practicability. Wei et al. (2019) put forward a calculation and evaluation method for the operation energy efficiency of cold water air-conditioning units based on the electric load rate. The piecewise least square method was used to fit the relationship between the electric load rate and the energy efficiency ratio of the chiller. Then the energy efficiency ratio curve is plotted to complete the online assessment of energy efficiency.

Aiming at the problems of low evaluation accuracy and long evaluation time in the existing evaluation methods of air-conditioning cold source energy efficiency, this paper proposes an evaluation method of intelligent building refrigeration and air-conditioning cold source energy efficiency based on the improved entropy method. The specific research ideas of this paper are as follows:

1 First analyse the energy efficiency ratio composition of refrigeration and air conditioning system, and then calculate the energy efficiency ratio of air conditioning system operation. In order to improve the calculation accuracy of the energy efficiency ratio of the cold source of the building refrigeration and air conditioning, and to improve the accuracy of the evaluation results to a large extent, the energy efficiency ratio calculation process is refined by using the refrigeration energy efficiency transport function.

2 The improved entropy method of AHM was used to optimise the weight matching process to fundamentally improve the accuracy of the evaluation. Then the subjective weight and objective weight of the evaluation index of cold source energy efficiency of refrigeration and air conditioning were calculated, and the cold source energy efficiency of refrigeration and air conditioning was evaluated by adjusting the weight ratio.

2 Evaluation of energy efficiency of refrigeration and air conditioning in intelligent building based on improved entropy method

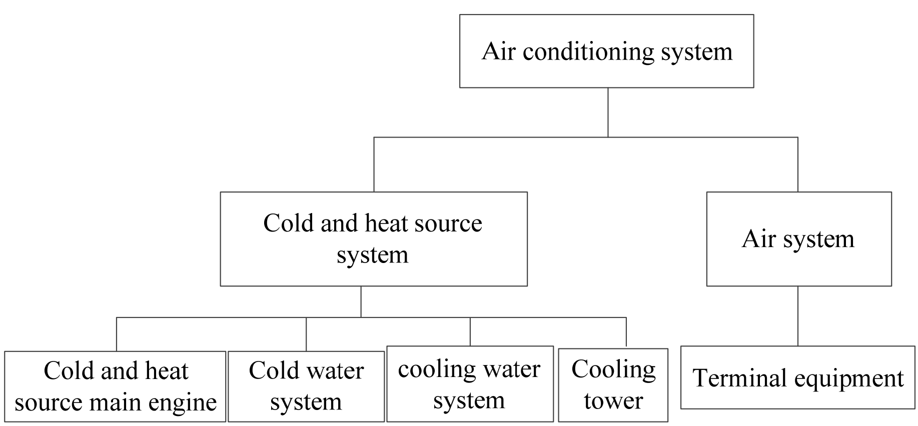
The research idea of this chapter is as follows: firstly, the energy efficiency ratio of the cold source of refrigeration and air conditioning in the intelligent building is calculated. In order to effectively improve the energy evaluation efficiency, the energy efficiency ratio calculation process is refined. In order to improve the accuracy of the joint results, the AHM improved entropy method was used to optimise the weight matching process, and the subjective weight and objective weight of the evaluation index of cold source energy efficiency of refrigeration and air conditioning were calculated, and then the evaluation of the cold source energy efficiency of refrigeration and air conditioning was completed by adjusting the weight matching.

2.1 Analyse the energy efficiency ratio composition of refrigeration and air conditioning cold source in intelligent building

The cold source system of intelligent building refrigeration and air conditioning can be divided into two subsystems: the cold and heat source system and the wind system. Among them, the cold and heat source system includes the cold and heat source host, the cold water system, the cooling water circulation system and the cooling tower, the wind system includes the fan coil unit, the new fan, the combined air conditioner and other end equipment (Wei et al., 2019; Osipov et al., 2019).

In order to ensure that the energy efficiency ratio evaluation index can accurately evaluate the operation energy efficiency of the refrigeration and air conditioning system of the intelligent building, and it is simple and easy to operate, the operation energy efficiency of the system is evaluated from the whole air conditioning system and its subsystem. The structure of the cold source energy efficiency evaluation system for refrigeration and air conditioning in intelligent buildings is shown in Figure 1.

Figure 1 Energy efficiency ratio composition of refrigeration and air conditioning cold source for intelligent building



2.2 Calculate the energy efficiency ratio of cold source of refrigeration and air conditioning

Refrigeration energy efficiency ratio of air conditioning system is an important index to evaluate the refrigeration effect of air conditioning. If all the energy provided to the refrigeration and air conditioning is provided by electric energy, then the energy efficiency ratio of cold source of refrigeration and air conditioning of intelligent building (EER_s) can be calculated by formula (1) :

$$EER_s = \frac{Q}{\sum N_i} \tag{1}$$

In equation (1): Q represents the total refrigeration amount of building refrigeration and air conditioning; $\sum N_i$ represents the annual power consumption of air conditioning including cooling tower, water chiller and other equipment (Ding et al., 2020; Monteiro et al., 2020).

The above process is a relatively rough calculation method, and the process is relatively general. In order to improve the calculation accuracy of the cold source energy efficiency ratio of building refrigeration and air conditioning, and to reduce the total time of the evaluation process to a large extent, the following refined design of the calculation process of the cold source energy efficiency ratio is carried out.

First, we set the energy efficiency ratio of cold source of building refrigeration and air conditioning under different working conditions as EER_s , then the relationship between the energy efficiency ratio of cold source of air conditioning and the refrigeration energy consumption load rate can be expressed as:

$$EER_{si} = \frac{Q_{si}}{p_{si}} \tag{2}$$

In equation (2) : i represents each stage of load rate under different working conditions; s stands for air conditioning refrigeration system; Q_{si} represents the cooling capacity of each stage of the air conditioning refrigeration system; p_{si} represents the total energy consumption of air-conditioning refrigeration system including cooling tower, water chiller and other equipment (Lin and Chen, 2020; Jones and Josephine, 2020). At this point, the total energy consumption of refrigeration and air conditioning of intelligent building can be expressed as the sum of the power consumption p_{ji} of air-conditioning refrigeration unit and the power consumption p_{qi} of other auxiliary equipment, namely:

$$p_{si} = p_{ji} + p_{qi} \tag{3}$$

In equation (3): j represents air conditioning refrigeration unit. For the air-conditioning refrigeration system, if the heat transfer coefficient is a constant value, the energy consumption of the cold capacity transfer chain p_{qe} and p_{qi} are always equal, that is, $p_{qi} = p_{qe}$, then there is:

$$p_{si} = p_{qi} + p_{qe} \tag{4}$$

When all chillers of refrigeration and air conditioning are running at full capacity, suppose m represents the percentage of energy consumption of the whole refrigeration unit and total energy consumption of refrigeration and air conditioning, then:

$$p_{je} = p_{se} \times m \Rightarrow p_{se} = \frac{p_{je}}{m} \tag{5}$$

$$p_{qe} = p_{se} \times (1-m) = \frac{p_{je}}{m} \times (1-m) \tag{6}$$

$$EER_{si} = \frac{Q_{si}}{p_{je} + \frac{p_{je}}{m} \times (1-m)} = \frac{1}{\frac{p_{ji}}{Q_{si}} + \frac{p_{je}}{Q_{si}} \times \frac{(1-m)}{m}} \tag{7}$$

$$Q_{si} = Q_{max} \times N_i = Q_{se} \times N_i \tag{8}$$

In the above formulas, Q_{max} represents the maximum refrigeration load of the energy efficiency of the cold source of building refrigeration and air conditioning; N_i represents energy efficiency loss of operating parameters of air conditioning cold source in intelligent building. At this time, the following formula can be used to calculate the energy efficiency ratio COP of the air conditioning refrigeration unit at full load and the energy efficiency ratio $\mathrm{COP_i}$ of the air conditioning refrigeration unit under other working conditions:

$$\mathrm{COP_i} = \frac{Q_{si}}{p_{ji}} \tag{9}$$

$$\mathrm{COP} = \frac{Q_{se}}{p_{je}} \tag{10}$$

$$\frac{p_{je}}{Q_{si}} = \frac{p_{je}}{Q_{se} \cdot N_i} = \frac{1}{\frac{Q_{se}}{p_{je}} \cdot N_i} \tag{11}$$

In equation (11), Q_{se} represents the transport function of air conditioning refrigeration energy efficiency. By sorting out Formula (7) to Formula (11), the final energy efficiency ratio of cold source of refrigeration and air conditioning for intelligent building can be obtained as follows:

$$EER_{si} = \frac{1}{\frac{1}{\mathrm{COP_i}} + \frac{1}{N_i \cdot \mathrm{COP}} \cdot \frac{1-m}{m}} \tag{12}$$

Thus, the energy efficiency ratio calculation of cold source of refrigeration and air conditioning in intelligent buildings is realised, and the energy efficiency ratio calculation process is given, which effectively improves the effect of subsequent energy efficiency evaluation of cold source of refrigeration and air conditioning.

2.3 The improved entropy method is used to evaluate the energy efficiency of refrigeration air conditioning

Using the above calculation results of energy efficiency ratio of cold source of refrigeration and air conditioning, this paper uses the improved entropy method to construct the evaluation matrix of energy efficiency of cold source of air conditioning:

$$X = \left(X_{ij} \right)_{m \times n} \tag{13}$$

In equation (13), X represents the original data matrix of the evaluation matrix of air conditioning cold source energy efficiency; X_{ij} represents the weight index of the cold source energy efficiency evaluation matrix; The number of changes in energy efficiency of air-conditioning cold source refrigeration is represented by m; n represents the number of cold capacity transfer chains for cold source energy efficiency.

The parameters of the cold source energy efficiency evaluation matrix are processed by the same degree quantisation method to obtain the impact weight of the i link of the refrigeration energy consumption loss in the j item (Wang et al., 2020). The calculation formula of the impact weight of the refrigeration energy consumption is as follows:

$$P_{ij} = X_{ij} \diagup \sum_{i=1}^{m} X_{ij} \tag{14}$$

In equation (14), P_{ij} represents the power consumption of the refrigerating air conditioner. At this time, the entropy value of the energy consumption factor affecting item j of the refrigeration air conditioner is calculated as follows:

$$e_j = -k \sum_{i=1}^{m} p_{ij} lnp_{ij} \tag{15}$$

In equation (15), e_j represents the entropy value of energy consumption influencing factor of item j of refrigeration air conditioning cooler, and $e_j \geq 0, k > 0$, $k = 1 / ln\, m$. Based on this, the inverse Carnot cycle theory is used to obtain the difference coefficient of influencing factors on energy consumption at this time. The process is as follows:

$$g_j = 1 - e_j \tag{16}$$

In equation (16), g_j represents the difference coefficient of energy consumption influencing factors. Then, after obtaining the relative weights among different influencing factors of refrigeration energy consumption, the mean weight of the refrigeration energy consumption was obtained through iterative calculation:

$$w_j = g_j / \sum_{i=1}^{n} g_j \tag{17}$$

In order to obtain more accurate weights of intelligent building energy efficiency in refrigeration and air conditioning cold source, through the way of AHM and entropy value method to get air conditioning cold source subjective weight and objective weight of energy efficiency, and finally is obtained by calculation of the intelligent building energy efficiency in refrigeration and air conditioning cold source price index weight, and according to the ratio of weight value to obtain the final evaluation results of energy efficiency.

AHM is a kind of attribute hierarchy model, which can directly calculate the relative attribute weight in the comparison matrix, which effectively makes up for the deficiency of AHP method. The first layer is the target layer, which is used to search for the best evaluation target; the second layer is the index layer, which includes all the evaluation indexes; the third layer is the scheme layer, which is used to complete the performance evaluation. Elements in each layer can be used as rules to govern the elements associated with them in the next layer. By combining AHM with entropy method, the final evaluation process is obtained as follows:

$$Z = \left(\mu W_{AI} + (1-\mu) W_{BI}\right) \times EER_{si} \tag{18}$$

In equation (18), W_{AI} represents the objective weight of energy efficiency of cold source of refrigeration and air conditioning in intelligent buildings; W_{BI} represents the subjective weight of energy efficiency of cold source of refrigeration and air conditioning in smart buildings; μ denotes the cooling source energy adjustment coefficient of refrigeration and air conditioning, and its value is related to objective environmental factors, $\mu \in [0.5,1]$. If the user's external environment is dominant; When the user's idea is dominant, $\mu \in [0.5,1]$.

To sum up, on the basis of analysing the energy efficiency ratio composition of refrigeration and air conditioning system, in order to improve the accuracy of subsequent evaluation results, this study used the refrigeration energy efficiency transport function to carry out fine processing on the calculation process of energy efficiency ratio. Based on this, the AHM improved entropy method was used to optimise the weight matching process, and the subjective weight and objective weight of the evaluation index of cold source energy efficiency of refrigeration and air conditioning were calculated, and then the evaluation of the cold source energy efficiency of refrigeration and air conditioning was completed by adjusting the weight matching.

3 Experiment and analysis

3.1 Design of experimental scheme

In order to verify the feasibility of the evaluation method of cold source energy efficiency of intelligent building refrigeration and air conditioning based on the improved entropy value method designed in this paper, the following experiments are designed.

In the experiment, an intelligent building was selected as the experimental object for the evaluation of the energy efficiency of the cold source of building refrigeration and air conditioning. The intelligent building has 12 floors (two underground and 10 above ground). Take the 6th, 7th and 8th floors of the building as an example, there are activity rooms with an area of 300 m^2 in the 6th floor, conference rooms with an area of 200 m^2 in the 7th floor, and offices with an area of 50 m^2, 80 m^2 and 100 m^2 in the 8th floor. The data are mainly from indoor machines and central refrigerators. Unit data length is 107bit. In this environment, method of Sheng et al. (2019), method of Zhao et al. (2020), method of Tang (2020) and method of this paper are respectively used to analyse the energy efficiency of cold source of refrigeration and air conditioning in this building.

3.2 Design of experimental indicators

1 Evaluation accuracy of cold source energy efficiency: This index is a basic index, which can directly reflect the effectiveness of the evaluation method. The higher the evaluation accuracy is, the stronger the effectiveness of the evaluation method is. On the contrary, the lower the evaluation accuracy, the worse the effectiveness of the evaluation method.

2 Evaluation accuracy of cold source energy efficiency: this index is a comprehensive index, which refers to the degree of consistency between the evaluation results of each group and the degree of proximity to the truth value. It is a comprehensive concept of accuracy and correctness. The higher the evaluation accuracy is, the better the evaluation effect is. On the contrary, the lower the evaluation accuracy, the worse the evaluation effect of the evaluation method.

3.3 Experimental results and analysis

In this section, method of Sheng et al. (2019), method of Zhao et al. (2020), method of Tang (2020) and method of this paper will be analysed from two perspectives of the accuracy and precision of the evaluation of cold source energy efficiency The application performance of paper was tested.

3.3.1 Accuracy test of cold source energy efficiency evaluation

Firstly, the evaluation accuracy of method of Sheng et al. (2019), method of Zhao et al. (2020), method of Tang (2020) and method of this paper are tested to verify the effectiveness of different methods. The evaluation accuracy of cold source energy efficiency is shown in Table 1.

Table 1 Comparison results of evaluation accuracy of cold source energy efficiency by different methods

Built-up area /m^2	*Accuracy rate of refrigeration and air conditioning cold source energy efficiency evaluation /%*			
	Method of Sheng et al. (2019)	*Method of Zhao et al. (2020)*	*Method of Tang (2020)*	*Method of this paper*
50	76.0	79.5	82.0	98.2
80	75.8	76.2	79.9	98.0
100	72.6	74.6	78.6	97.5
150	69.2	70.3	76.8	95.2
200	65.8	67.2	70.2	93.9
300	63.2	64.1	63.9	90.7
Value	70.4	72.0	75.2	95.9

According to the results shown in Table 1, with the increase of the floor area, the evaluation accuracy of cold source energy efficiency of refrigeration and air conditioning using different methods differs. When the building area is 50m^2, the evaluation accuracy rate of the cold source energy efficiency of method of Sheng et al. (2019) is 76.0%, and that of method of Zhao et al. (2020) is 79.5%. The evaluation accuracy of cold source energy efficiency by method of Tang (2020) is 82.0%, while the evaluation accuracy of cold source energy efficiency by method of this paper is 98.2%. When the building area increases to 300m^2, method of Sheng et al. (2019), method of Zhao et al. (2020), method of Tang (2020) and method of this paper. The accuracy rate of evaluation of air conditioning cold source energy efficiency by Paper was reduced to 63.2%, 64.1%, 63.9 and 90.7%, respectively. From the perspective of average value, the average evaluation accuracy of method of this paper is 95.9%, indicating that the evaluation accuracy of method of this paper is always significantly higher than that of the three traditional methods for air conditioning cold source energy efficiency, proving its higher effectiveness.

3.3.2 Refrigeration and air conditioning cold source energy efficiency evaluation accuracy test

In order to verify the evaluation efficiency of refrigeration and air conditioning cold source energy efficiency of the method presented in this paper, the method of Sheng et al. (2019), method of Zhao et al. (2020), method of Tang (2020) and method of this paper presented in this paper were used to conduct the evaluation accuracy test of cold source energy efficiency, and the results were shown in Table 2.

Table 2 Comparison of evaluation accuracy of refrigeration and air conditioning cold source energy efficiency under different methods

Built-up area /m^2	*Evaluation accuracy of cold air conditioning cold source energy efficiency /%*			
	Method of Sheng et al. (2019)	*Method of Zhao et al. (2020)*	*Method of Tang (2020)*	*Method of this paper*
50	91.1	79.8	93.4	96.8
80	82.1	73.6	92.4	95.3
100	87.2	80.1	91.7	97.0
150	83.2	76.3	94.5	98.6
200	89.6	78.2	90.7	94.3
300	88.2	77.6	92.3	95.8
Value	86.9	77.6	92.5	96.3

According to the results shown in Table 2, with the increase of the floor area, the evaluation time of the cold source energy efficiency of refrigeration and air conditioning of different methods also changes, but no fixed rule has been found yet. When the building area is 50 m^2, the evaluation accuracy of the air conditioning cold source energy efficiency of method of Sheng et al. (2019) is 91.1%, and that of method of Zhao et al. (2020) is 79.8%. The evaluation accuracy of the air conditioning cold source energy efficiency by method of Tang (2020) is 93.4%, and the evaluation time of the air conditioning cold source energy efficiency by method of this paper is 96.8%. When the building area increases to 300 m^2, method of Sheng et al. (2019), method of Zhao et al. (2020), method of Tang (2020) and method of this paper, the accuracy of the evaluation of air conditioning cold source energy efficiency by Paper is 88.2%, 77.6%, 92.3% and 95.8%, respectively. From the perspective of average value, the average evaluation time of method of this paper is 96.3%, indicating that the evaluation accuracy of method of this paper is higher and the evaluation effect is better.

In conclusion, the experimental verification shows that the average evaluation accuracy and accuracy of the proposed method are superior to the traditional methods after it is applied to the evaluation of the energy efficiency of the cold source of refrigeration and air conditioning in intelligent buildings. The above results prove that the proposed method has a strong application advantage.

4 Conclusion

In order to improve the evaluation accuracy and shorten the evaluation time, this paper proposes an evaluation method for the energy efficiency of refrigeration and air conditioning in intelligent buildings based on the improved entropy method. On the basis of analysing the energy efficiency ratio composition of refrigeration and air conditioning system, the calculation process of energy efficiency ratio is refined by using refrigeration energy efficiency transport function. Then, AHM improved entropy method is used to calculate the subjective weight and objective weight of the evaluation index of cold source energy efficiency of refrigeration and air conditioning, and the evaluation of the cold source energy efficiency of refrigeration and air conditioning is completed by adjusting the weight ratio.

Through experiments, this paper draws the following conclusions: the average evaluation accuracy of the proposed method is 95.9%, and the average evaluation accuracy is 96.3%, both of which are superior to the traditional evaluation methods. In the following research, the method in this paper will be further optimised to further expand its application scope.

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