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User Energy Efficiency Evaluation Model Based on Comprehensive Weighting Method of the PCA and G1 Methods

Di Jian, Xing Rui

College of Control and Computer Engineering, North China Electric Power University, Baoding 071003, Hebei Province, China

Abstract: Aiming at the high energy consumption level of power demand side, the general model of energy consumption index analysis is established to evaluate the energy efficiency level of power users, and provide the theoretical basis for energy saving and emission reduction and energy utilization. Based on the PCA method and the improved G1 method, the model integrates the evaluation index, and on this basis, the comprehensive evaluation model of energy efficiency is put forward, which brings together the comprehensive advantages of subjective and objective empowerment and rationally adopts the subjective information of decision makers, Which ensures the scientific and reliability of the evaluation model and effectively avoids the limitation of single weight. The example shows that the improved PCA method and the G1 method of the comprehensive weighting method of the evaluation model, high reliability, fast calculation, with strong practical value.

Keywords: PCA method, G1 method, comprehensive empowerment, index evaluation

1. INTRODUCTION

The development of electricity equipment and the gradual popularization, to promote the vigorous development of China's power industry, and the consumption of electricity has been increasing rapidly. According to the International Energy Agency in the "Global Energy Outlook Report" estimates: China's electricity demand in 2030, an annually increase of 4.5%. Although the state invested heavily in the transformation of a large number of power plants and substations, but the power shortage situation is still slow to slow down, electricity load is still climbing, the dependence on energy and consumption increased rapidly. So China's energy demand side of a large space for energy-saving, energy demand side to achieve energy-saving emission reduction has significant social benefits.

Energy efficiency assessment is an important research content of energy conservation and emission reduction. It can scientifically evaluate the energy efficiency of electric power users, fully understand the energy consumption of power enterprises, find energy consumption problems, tap energy saving potential, formulate reasonable energy saving schemes, providing comprehensive and scientific basis for the whole society of energy saving and emission reduction.

In the literature [3] Li Xiang proposed a hierarchical analysis based on the analysis of different indicators of the relationship between the layers of the model and the relationship between the model established to rely on expert advice, but only the application of less energy efficiency system; In the literature [5] matrix operator and "block multiplication" matrix operation are introduced to establish the energy efficiency analysis model of thermodynamic system under multiple disturbance. In the literature [9], proposed a model based on comprehensive sensitivity to determine the model and design evaluation algorithm, but the sensitivity analysis is too dependent on the experimental data, the model is difficult to guarantee the effectiveness. In the literature [10], BP neural network and principal component analysis are combined to propose an energy efficiency prediction model for ore rock blasting. Most of the researches on energy efficiency index system of power enterprises are large short board.

In order to improve the scientific nature of the index weight in the energy efficiency assessment and reduce the deviation of the single weight of the index, and fully integrate the subjective and objective evaluation information, this paper investigates the large amount of data, establishes the energy efficiency evaluation model combined with the PCA method and the G1 method, effective assessment of energy efficiency on the demand side.

2. RELATED DEFINITIONS

2.1 PCA method

PCA method, that is, principal component analysis, mainly used in power system state estimation, transformer fault diagnosis and load forecasting. The idea is to reduce the number of variables into independent of each other can represent the original variable of the integrated variables, with high statistical performance.

PCA completely rely on objective data feature method to determine the weight, the calculation principle is:

Suppose there are n index sets, each with p evaluation index, evaluation index data set is $X=\left(X_{\mathrm{ij}}\right)_{\mathrm{n*p}}$, X_{ij} that the i index set the value of the first j index. And then standardize the standard processing

$$Z_{\mathrm{ij}}=\frac{X_{\mathrm{ij}}-\overline{\mathrm{X}}_{\mathrm{j}}}{S_{\mathrm{j}}} \tag{1}$$

$\overline{X}_j, \overline{S}_j$ is the mean and mean square of the j index, $\overline{X}_j=\frac{1}{n}\sum_{i=1}^{n}X_{ij}$, $\overline{S}_{\mathrm{j}}=\sqrt{\frac{1}{\mathrm{n}}\sum_{\mathrm{i=1}}^{\mathrm{n}}\left(X_{\mathrm{ij}}-\overline{X}_{\mathrm{j}}\right)^2}$

And then calculate the correlation coefficient matrix R, $R=\left(r_{ij}\right)_{p\times p}$ of z_{ij}, r_{ij} is the degree of correlation between the indicators z_i and z_j. Assuming that R has q is greater than 0, the eigenvalue $\lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_q \geq 0$, the eigenvalues correspond to the normalized orthogonal eigenvectors $A=\left(a_1, a_2, \cdots a_q\right)$, q principal components are

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_q \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{p1} \\ a_{12} & a_{22} & \cdots & a_{p2} \\ \vdots & \vdots & \vdots & \vdots \\ a_{1q} & a_{2q} & \cdots & a_{pq} \end{bmatrix} \begin{bmatrix} Z_1 \\ Z_2 \\ \vdots \\ Z_P \end{bmatrix} \tag{2}$$

Written in matrix form:

$$Y = A^T Z \tag{3}$$

The principal component properties are:

$$\operatorname{cov}\left(y_i, y_j\right) = \begin{cases} 0(i \neq j) \\ \lambda_i (i = j) \end{cases} \tag{4}$$

The formula (4) shows that the principal components are independent of each other, and the derivation process deconstructs the decay of the index variables, and the eigenvalue λ_1 of the i-th principal component y_i is the variance of the principal component, and its contribution to the total variance is:

$$w_i = \frac{\lambda_i}{\sum_{j=1}^{n} \lambda_j} \tag{5}$$

w_i is the percentage of the original variable information carried by the i-th principal component, the w_i of the principal component decreases in turn, and the cumulative variance contribution ρ of the former m principal components is:

$$\rho = \frac{\sum_{i}^{m} \lambda_i}{\sum_{j=1}^{n} \lambda_j} \tag{6}$$

The selection of the number of principal components m is based on the ρ of the principal component, and the predetermined ρ is greater than 85% to ensure that it contains most of the information of the original data.

2.2 G1 method

The method of determining the weight of AHP is a kind of subjective experience judgment method, which does not need to construct the judgment matrix. The calculation is small and does not limit the number of indicators in the same level, which is divided into three steps:

2.2.1 Determine the order relationship

(1) If the degree of importance of the evaluation index x_i relative to an evaluation criterion is greater than or equal to x_i, then $x_i > x_j$;

(2) If the evaluation index $x_1, x_{2\ldots} x_m$ has a relational expression

$$x_1^* \succ x_2^* \succ \cdots x_m^* \tag{7}$$

relative to an evaluation criterion, the order relationship is established according to "$\succ$". x_i^* is the i-th evaluation index (i =1,2,......,m) after the order of the $x_1, x_2, \cdots, x_m$ order relation "$\succ$". The formula (7) is recorded as

$$x_1 \succ x_2 \succ \cdots \succ x_m \tag{8}$$

2.2.2 Determine the relative importance of the degree

Assuming that the degree of importance of the expert to the evaluation index x_{k-1} and x_k is

$$\frac{w_{k-1}}{w_k},\ r_k = \frac{w_{k-1}}{w_k} \tag{9}$$

$k = m, m-1, m-2, \cdots, 3, 2$

When m is large, (8) desirable $r_m = 1$. r_k assignment reference Table 1:

Table 1 r_k assignment

r_k	Description
1.0	Indicators x_{k-1} and x_k are equally important
1.2	Indicators x_{k-1} and x_k are slightly important
1.4	Indicators x_{k-1} and x_k are obviously important
1.6	Indicators x_{k-1} and x_k are strongly important
1.8	Indicators x_{k-1} and x_k are extremely important

The number of constraints between r_k is: if $x_1, x_2, \cdots, x_m$ has the order relation (7), then

$$r_{k-1} > \frac{1}{r_k},\ k = m, m-1, m-2, \cdots, 3, 2 \tag{10}$$

2.2.3 Calculate the index weight coefficient w_k

On the basis of 2.2.1 and 2.2.2, can get

$$w_m = \left(1 + \sum_{k=2}^{m} \prod_{i=k}^{m} r_i\right)^{-1} \tag{11}$$

Recursive available: $w_{k-1} = r_k w_k$, $k = m, m-1, m-2, \cdots, 3, 2$

From the above three steps can be based on the G1 method of the index weight set

$$w = \left(w_1, w_2, \cdots, w_m\right) \tag{12}$$

3. COMPREHENSIVE WEIGHTING METHOD BASED ON PCA AND

PCA method to determine the weight completely dependent on the original database, doping subjective factors, and objectivity is too strong; when the weight is determined by the G1 method, the unique ordinal relation between the indexes given by experts is used, subjective strong. So the combination of the two characteristics, a more rational method of weight allocation is established.

3.1 Linear weighting method

In order to avoid the limitation of the single empowerment of the two, we can linearize the two to establish the formula: $w^{*}=\alpha w+(1-\alpha)\partial$, w^{*} is the comprehensive weight, α is the subjective preference coefficient, the interval is [0,1], the specific value is given by the expert According to experience, $(1-\alpha)$ is the objective preference coefficient.

The linear weighting method integrates the advantages of the PCA and G1 methods, but does not completely eliminate their own shortcomings. PCA to determine the weight of the principal component of the variance contribution rate, we must ensure that the cumulative contribution of the previous few main components to a higher level in order to make the extracted main components in line with practical significance, and its interpretation of ambiguity, the original variable Meaning inaccurate, so the number of extracted principal components is significantly smaller than the original variable, otherwise it is not conducive to dimensionality. And the direct use of linear combination does not rule out this possibility, may not be fully consistent with the objective reality; G1 method depends on the expert to determine the relationship between the order of the weight, if the expert based on experience given the order relationship unreasonable, will lead to unreasonable weight distribution.

3.2 Comprehensive empowerment law

Based on the above understanding, we propose a combination weighting method (comprehensive weighting method based on PCA and G1 method). The specific steps are:

The original index data with the trend of the transformation of $X=\left(x_{ij}\right)_{n\times p}$, from the formula (1), (6) and the principal component properties of $Z=\left(Z_{ij}\right)_{n*p}$, then calculate the mean covariance matrix covariance matrix $S=\left(S_{ij}\right)_{n*p}$

$$S_{ij}=\frac{1}{n-1}\sum_{i=1}^{n}(z_{h}-z_{i})(z_{ij}-z_{j}) \tag{13}$$

Where $z_{i}=\frac{1}{n}\sum_{i=1}^{n}z_{h}$, and then the principal component analysis is performed according to the covariance matrix. The flow chart shown in Figure 1:

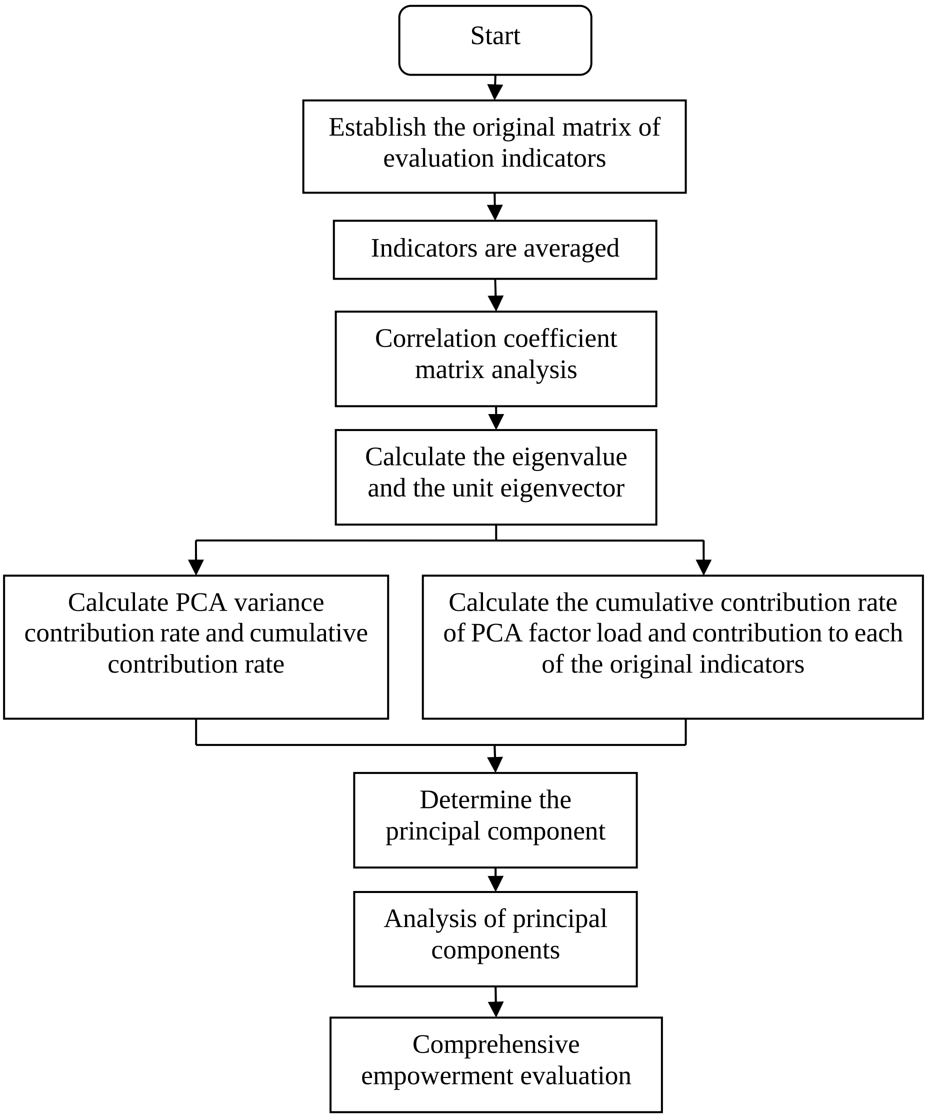

Figure 1 The process of principal component analysis

The weight of each index is calculated from the covariance matrix and (6): $\vartheta = (\mu_1, \mu_2, \cdots, \mu_h, v_1, v_2, \cdots, v_{m-h})^T$.

According to the relationship between the size of the index weight to determine the only importance between the order of relations, as shown in equation (7); experts give the degree of importance between the adjacent indicators to determine the value of r_k reference table 1.

By the formula (5) and (6) to calculate the weight of each index, based on the PCA and G1 method of the overall weight of the indicators:

$$w_i = \frac{\alpha_i w_{si} + \beta_i w_{oi}}{\sum_{i=1}^{m} (\alpha_i w_{si} + \beta_i w_{oi})},\ 1 \le i \le n \tag{14}$$

The weights of the indicators after comprehensive empowerment are:

$$w^{**} = (w_1, w_2, \cdots, w_m) .$$

4. CASE STUDY

4.1 Establishment of primary selection indicators

The energy consumption of the energy efficiency assessment model is based on the data of a province's power company. The evaluation angle is energy cost, power information, safety energy and energy pollution. In turn, it includes 6 items, 8 items, 7 items and 4 evaluation indexes, a total of 25 items. As shown in Table 2:

Table 2 Primary index system

<table>
<tr><th>Evaluation</th><th>First level index</th><th>Two level evaluation index</th></tr>
<tr><td rowspan="6">Cost of energy</td><td rowspan="3">Reasonable cost</td><td>Penalty rates</td></tr>
<tr><td>Time-of-day electricity</td></tr>
<tr><td>Basic electricity</td></tr>
<tr><td rowspan="2">Loss balance</td><td>Power consumption rate</td></tr>
<tr><td>Fluctuation of electricity consumption rate</td></tr>
<tr><td>Equipment energy consumption</td><td>Equipment energy consumption anomalies</td></tr>
<tr><td rowspan="8">Power information</td><td rowspan="2">Electricity</td><td>Transformer load factor</td></tr>
<tr><td>Phase voltage</td></tr>
<tr><td rowspan="6">Power information</td><td>Phase power factor</td></tr>
<tr><td>Phase power factor</td></tr>
<tr><td>Three - phase current unbalance</td></tr>
<tr><td>Cumulative load overload time</td></tr>
<tr><td>Cumulative time of voltage failure</td></tr>
<tr><td>Load rate</td></tr>
<tr><td rowspan="7">Safe energy utilization</td><td rowspan="3">Device alarm</td><td>Communication anomaly</td></tr>
<tr><td>Device exception</td></tr>
<tr><td>Metric abnormalities</td></tr>
<tr><td rowspan="3">Platform warning</td><td>Voltage pass rate</td></tr>
<tr><td>Three-phase imbalance</td></tr>
<tr><td>Power factor distribution</td></tr>
<tr><td>Production safety</td><td>Harmonic situation</td></tr>
<tr><td rowspan="4">Energy pollution</td><td rowspan="3">Energy pollution</td><td>Electromagnetic pollution</td></tr>
<tr><td>Harmonic content</td></tr>
<tr><td>Loss of electricity</td></tr>
<tr><td>Energy consumption</td><td>Energy consumption per unit area</td></tr>
</table>

4.2 Energy efficiency index screening based on principal component analysis

The main component analysis of the energy efficiency index data, the corresponding eigenvalues, the corresponding variance contribution rate and cumulative variance contribution rate of each principal component are shown in Table 3:

Table 3 Principal component $Y_1 \sim Y_4$ eigenvalue and variance contribution rate

Principal component	Eigenvalue root λ	Variance contribution rate $\alpha/\%$	Cumulative variance tribute $\beta/\%$
Y_1	1, 7885	40.41	40.41
Y_2	1.5682	35.44	75.85
Y_3	0.5898	13.33	89.18
Y_4	0.4410	9.97	99.14

Calculated by the formula (6), the contribution rate of each principal component to the index is shown in Table 4:

Table 4 The contribution rate of principal components to each index

Index	$\rho^{(1)}$	$\rho^{(2)}$	$\rho^{(3)}$	$\rho^{(4)}$
X_1	0..0095	0.2475	0.7560	0.9143
X_2	0.3238	0.0894	0.2484	0.2605
X_3	0.3238	0.3521	0.3571	0.9443
X_4	0.3117	0.3838	0.3983	0.9299
X_5	0.1359	0.7407	0.7811	0.9482
X_6	0.3483	0.9705	0.9722	0.9995
X_7	0.0265	0.0276	0.7906	0.9869
X_8	0.0337	0.0276	0.8089	0.9826
X_9	0.0537	0.1485	0.7900	0.9958
X_{10}	0.8021	0.9607	0.9617	0.9947
X_{11}	0.2865	0.2910	0.9672	0.9984
X_{12}	0.1119	0.5943	0.9561	0.9932
X_{13}	0.3215	0.8861	0.7900	0.9354
X_{14}	0.2546	0.6524	0.8652	0.9891
X_{15}	0.4512	0.6912	0.7956	0.9659

We can see the first four principal components of the contribution rate of each index are high, can be extracted. After screening the remaining two energy efficiency indicators of the remaining 20, as shown in Table 5:

Table 5 Energy efficiency index after screening by PCA

Evaluation	First level index	Two level evaluation index
Cost of energy	Reasonable cost	Penalty rates
		Time-of-day electricity
	Loss balance	Power consumption rate
		Fluctuation of electricity consumption rate
	Equipment energy consumption	Equipment energy consumption anomalies
Power information	Electricity	Transformer load factor
		Phase voltage
	Power information	Phase power factor
		Phase power factor
		Three - phase current unbalance
		Cumulative load overload time
		Cumulative time of voltage failure
		Load rate
Safe energy utilization	Device alarm	Communication anomaly
		Device exception
		Metric abnormalities
		Three-phase imbalance
	Production safety	Harmonic situation
Energy pollution	Energy pollution	Electromagnetic pollution
		Harmonic content

4.3 Energy efficiency index screening based on G1 method

Here is a list of indicators that do not meet the consistency requirements of the index system screening. The order of the four secondary evaluation indexes in S1 is $x_1 \succ x_4 \succ x_3 \succ x_2$, which is $x_1^{'} \succ x_2^{'} \succ x_3^{'} \succ x_4^{'}$, where $r_2 = w_1^{'} / w_2^{'} = 1.6$, $r_3 = w_2^{'} / w_3^{'} = 1.2$, $r_4 = w_3^{'} / w_4^{'} = 1.4$, $w_1^{'}$, $w_2^{'}$, $w_3^{'}$, $w_4^{'}$ represent the evaluation index $x_1^{'}$, $x_2^{'}$, $x_3^{'}$, $x_4^{'}$ of the weight coefficient, by the formula (5) and (6) available:

$$w_4^{'} = (1+5.786)^{-1} = 0.1477,\ w_3^{'} = w_4^{'} * r_4 = 0.2086,\ w_2^{'} = w_3^{'} * r_3 = 0.2482,$$
$$w_1^{'} = w_2^{'} * r_2 = 0.3972,\ w_1 = w_1^{'} = 0.3972,\ w_2 = w_4^{'} = 0.1477,\ w_3 = w_3^{'} = 0.2068,$$
$$w_4 = w_2^{'} = 0.2482$$

After the screening, the index system contains 19 secondary indicators. The final energy efficiency evaluation index system is shown in Table 6:

Table 6 The energy efficiency index after screening by eigenvalue method and G1 method

Evaluation	First level index	Two level evaluation index
Cost of energy	Reasonable cost	Penalty rates
		Time-of-day electricity
	Loss balance	Power consumption rate
		Fluctuation of electricity consumption rate
	Equipment energy consumption	Equipment energy consumption anomalies
Power information	Electricity	Transformer load factor
		Phase voltage
	Power information	Phase voltage
		Three - phase current unbalance
		Cumulative load overload time
		Load rate
		Device exception
		Metric abnormalities
	Platform warning	Voltage pass rate
		Three-phase imbalance
		Power factor distribution
Energy pollution	Energy pollution	Electromagnetic pollution
		Harmonic content
	Energy consumption	Energy consumption per unit area

4.4 Based on the PCA and G1 method of comprehensive empowerment index screening

The actual evaluation process selected four experts, the establishment of the relationship between the order and the importance of indicators r_k such as Table 7:

Table 7 Ordinal relation and importance degree index

Expert serial number	Order relationship	r_2	r_3	r_4
1	$s_2 \succ s_1 \succ s_4 \succ s_3$	1.4	1.2	1.6
2	$s_1 \succ s_2 \succ s_3 \succ s_4$	1.0	1.2	1.2
3	$s_2 \succ s_1 \succ s_4 \succ s_3$	1.2	1.5	1.8
4	$s_3 \succ s_1 \succ s_2 \succ s_4$	1.6	1.2	1.4

By the comprehensive weighting method to filter the index after the remaining 16 indicators, the screening effect is better than the results of the single empowerment of the two, and the weight of the index is calculated according to the formula (14). The results are shown in Table 8:

Table 8 Indicators of screening and the weight of the secondary indicators

Evaluation angle	symbol	Number of indicators	one Level weight	Secondary weight
Cost of energy	s_1	4	0.2767	0.2614,0.2468,0.2369,0.2548
Power information	s_2	6	0.3096	0.3078,0.1128,0.1368,0.1508,0.1884,0.1016
Safe energy utilization	s_3	3	0.2210	0.2982,0.2169,0.4819
Energy pollution	s_4	3	0.1927	0.3364,0.4318,0.2318

4.5 Comparative analysis of the results

This paper analyzes the PCA, G1 method and the comprehensive weighting method of the two methods, which proves that the results of the comprehensive weighting method are more effective and the proportion of subjective and objective is more reasonable. The results are shown in Table 9:

Table 9 Experimental comparison results

algorithm / parameter	PCA method	G1 method	Comprehensive empowerment method
Index set	25	25	25
The remaining number of indicators after screening	20	19	16

5. COMPREHENSIVE EMPOWERMENT ASSESSMENT MODEL

By analyzing the comprehensive weighting method in Section 3.4, we establish a comprehensive weighting method to evaluate the model, and define the m principal component to form a comprehensive evaluation function

$$F = w_i x_{i1} + w_i x_{i2} + \cdots + w_i x_{im} \tag{15}$$

Among them, the principal component weight is the contribution rate of principal component variance. The comprehensive energy efficiency assessment model based on the weighting of the index weights selected by the comprehensive weighting method is:

$$\begin{aligned}
F &= 0.0724x_{11} + 0.0683x_{13} + \\
&0.0656x_{14} + 0.0795x_{15} + \\
&0.0953x_{21} + 0.0349x_{22} + \\
&0.0429x_{23} + 0.0467x_{24} + \\
&0.0583x_{26} + 0.0314x_{27} + \\
&0.0659x_{31} + 0.0479x_{33} + \\
&0.1072x_{34} + 0.0648x_{41} + \\
&0.0832x_{42} + 0.0447x_{43}
\end{aligned}$$

Three sets of calibration evaluation results were selected from the 20 energy efficiency data. The evaluation results are shown in Table 10:

Table 10 Comprehensive empowerment assessment results

User serial number	s_1	s_2	s_3	s_4	s
1	0.738	0.834	0.597	0.300	2.470
2	0.701	0.837	0.638	0.249	2.425
3	0.709	0.883	0.622	0.224	2.439

The evaluation results can be used as the basis for enterprise users to specify energy-saving programs, which is beneficial to users to fully tap energy-saving potential.

6. CONCLUSION

This paper analyzes the index screening process from the main and objective perspectives, combines the advantages of PCA and G1 method, establishes the comprehensive weighting method, and analyzes the same index set respectively to verify the validity of the comprehensive weighting method, which reduces the influence of the subjective factors in the evaluation process and provides a theoretical basis for the user's energy efficiency evaluation.

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