Evaluating energy saving system of data centers based on AHP and fuzzy comprehensive evaluation model

Yingni Jiang\textsuperscript{1, a}

\textsuperscript{1} Institute of equipment engineering, Engineering University of CAPF, Xi’an 710086, China

\textsuperscript{a} 13772146702@163.com

Abstract. Due to the high energy consumption of communication, energy saving of data centers must be enforced. But the lack of evaluation mechanisms has restrained the process on energy saving construction of data centers. In this paper, energy saving evaluation index system of data centers was constructed on the basis of clarifying the influence factors. Based on the evaluation index system, analytical hierarchy process was used to determine the weights of the evaluation indexes. Subsequently, a three-grade fuzzy comprehensive evaluation model was constructed to evaluate the energy saving system of data centers.

1. Introduction

Energy consumption of data centers accounts the main part of that of the communication network. Most of the old data centers have low energy efficiency because of poor design and technical level. Therefore, energy saving work of data centers is imminent. Scientific evaluation of energy saving of data centers is an important basis for carrying out communication energy conservation. Therefore, it is of great significance to establish an energy saving evaluation system of data centers.

Energy saving standards of data centers in developed countries have begun to take shape [1-3]. But different national conditions result in a big difference in evaluation indexes [4, 5]. And the suitable model to evaluate the energy saving system of data centers has never been reported till now.

This work tries to establish an energy saving evaluation index system of data centers of China. In addition, analytic hierarchy process and the fuzzy comprehensive evaluation method are used to evaluate this energy saving system of data centers. Finally, the validity of the model is verified by case study.

2. Constructing the evaluation index system

In this work, two first grade indexes, six second grade indexes and twenty-one third grade indexes are selected to construct the evaluation system. Table 1 shows the index system of energy saving system of data centers.
| Objectives | First grade indexes | Second grade indexes | Third grade indexes |
|------------|---------------------|----------------------|---------------------|
|            | Comprehensive energy efficiency | Energy efficiency | Power usage effectiveness (PUE) |
|            |                      | Safety stability     | Data center environment security |
|            |                      |                      | Communication network security |
| Energy saving evaluation of data centers A | Building thermal |                      | Location in layout |
|           |                      |                      | Heat insulation design of building envelope |
|           |                      |                      | Seal of building envelope |
|           | Equipment selection |                      | Communication equipment selection |
|           |                      |                      | Air conditioning equipment selection |
|           |                      |                      | Power equipment selection |
|           |                      |                      | Other equipment selection |
|           | Energy saving technology |                      | Communication system energy saving technology |
|           |                      |                      | Power system energy saving technology |
|           |                      |                      | Energy saving technology of air conditioning system |
|           |                      |                      | Other equipment energy saving technology |
|           |                      |                      | Green Building Technology |
|           |                      |                      | New energy technology |
|           | Green management     |                      | Statistical basis |
|           |                      |                      | Organization construction and operation |
|           |                      |                      | Specification establishment and Implementation |
|           |                      |                      | Green energy saving assessment |
|           |                      |                      | Improvement and promotion |

3. Determining weighting factors by AHP

3.1. Constructing judgment matrix (A)

The analytic hierarchy process method is applied to determine the weights of the various factors in Table 1. A judgment matrix (A) is established as follows:
$A = (a_{ij}) \ (i = 1,2,\ldots, \text{the number of layers}; \ j = 1,2,\ldots, \text{the number of elements})$

The term $a_{ij}$ represents the relative importance of $a_i$ compared to $a_j$, the value of $a_{ij}$ is determined by a 9-point scale [6].

3.2. Calculating the weights of evaluation indexes

In this work, six experts were invited to evaluate the impact of each index on the operation ability. Then the specific score of every indicator was gained on the basis of a percentage grading system. The results are shown in Table 2.

Table 2 Weights of the evaluation indexes.

(a) First grade indexes

| Name                        | Code | Weight |
|-----------------------------|------|--------|
| Comprehensive energy efficiency | B₁   | 0.3409 |
| Application of energy saving measures | B₂   | 0.6591 |

(b) Second grade indexes

| Name                        | Code | Weight |
|-----------------------------|------|--------|
| Energy efficiency           | C₁₁  | 0.2807 |
| Safety stability            | C₁₂  | 0.0602 |
| Building thermal            | C₂₁  | 0.0521 |
| Equipment selection         | C₂₂  | 0.1061 |
| Energy saving technology    | C₂₃  | 0.2883 |
| Green management            | C₂₄  | 0.2127 |

(c) Third grade indexes

| Name                                | Code | Weight |
|-------------------------------------|------|--------|
| Power usage effectiveness (PUE)     | D₁₁₁ | 0.2807 |
| Data center environment security    | D₁₂₁ | 0.0233 |
| Communication network security      | D₁₂₂ | 0.0369 |
| Location in layout                 | D₂₁₁ | 0.0137 |
| Heat insulation design of building envelope | D₂₁₂ | 0.0213 |
| Seal of building envelope           | D₂₁₃ | 0.0171 |
| Communication equipment selection   | D₂₂₁ | 0.0344 |
| Air conditioning equipment selection| D₂₂₂ | 0.0442 |
| Power equipment selection           | D₂₂₃ | 0.0228 |
| Other equipment selection           | D₂₂₄ | 0.0047 |
| Communication system energy saving technology | D₂₃₁ | 0.0557 |
| Power system energy saving technology | D₂₃₂ | 0.0849 |
| Energy saving technology of air conditioning system | D₂₃₃ | 0.0947 |
| Other equipment energy saving technology | D₂₃₄ | 0.0085 |
| Green Building Technology           | D₂₃₅ | 0.0140 |
4. The construction of a fuzzy comprehensive evaluation model

4.1. Determination of factor set
First, the evaluation factor set of energy saving system of data centers should be determined on the basis of Table 1. For example, the first grade factor set is \( U = \{B_1, B_2\} \).

4.2. Establishment of comments set
The comments set indicates different grades from low to high to reflect the performance of the evaluated object of various indexes. We can determine comments set as: \( V = \{V_1, V_2, V_3, V_4, V_5\} = \{\text{excellent, good, moderate, poor, bad}\} \). The comments set and the responding scores for energy saving system of data centers are shown in Table 3.

| Criteria                                      | excellent | good   | medium | poor   | worst |
|-----------------------------------------------|-----------|--------|--------|--------|-------|
| Scores of criteria                            | (80,100]  | (60,80] | (40,60] | (20,40] | [0,20] |

4.3. Determination of weight set
According to the weights of each evaluation index in Table 2, the weight set can be determined. For example, \( P_1 = [1] \), \( P_2 = [0.3869 \quad 0.6131] \), etc.

4.4. Determination of the fuzzy relationship matrix

4.4.1. Establishment of the membership function
The methods to determine membership function are varied [7]. In this paper, the membership function is selected as follows:

\[
r_{y1}(x) = \begin{cases} e^{-\frac{(x-90)^2}{100}} & x \in [0,80] \\ e^{-\frac{(x-100)^2}{200}} & x \in (80,100] \\ \end{cases} \tag{1}
\]

\[
r_{y2}(x) = e^{-\frac{(x-70)^2}{100^2}} \tag{2}
\]

\[
r_{y3}(x) = e^{-\frac{(x-50)^2}{100^2}} \tag{3}
\]

\[
r_{y4}(x) = e^{-\frac{(x-30)^2}{100^2}} \tag{4}
\]

\[
r_{y5}(x) = \begin{cases} e^{-\frac{x^2}{200^2}} & x \in [0,20) \\ e^{-\frac{(x-10)^2}{100^2}} & x \in [20,100] \\ \end{cases} \tag{5}
\]
where \( x \) is the index score, \( r_{x1}(x), r_{x2}(x), r_{x3}(x), r_{x4}(x), r_{x5}(x) \) are membership of the index score \( x \) belonging to the rank of \( V_1, V_2, V_3, V_4, V_5 \) respectively.

4.4.2. Determination of the fuzzy relationship matrix based on the membership function

(1) Comments set of single factor
Comments set of single factor consists of the membership of this factor belonging to the \( V_1, V_2, V_3, V_4, V_5 \) rank. The comments set \( r_{ik} \) of index \( D_{ik} \) is given as:

\[
r_{ik} = \left\{ r_{V1(ik)} , r_{V2(ik)} , r_{V3(ik)} , r_{V4(ik)} , r_{V5(ik)} \right\}
\]  

(6)

(2) Fuzzy relationship matrix
The fuzzy comprehensive evaluation matrix \( R_y \) of index \( C_y \) can be defined as follows:

\[
R_y = \begin{bmatrix}
    r_{y1} & r_{V1(y1)} & r_{V2(y2)} & r_{V3(y3)} & r_{V4(y4)} & r_{V5(y5)} \\
    r_{y2} & r_{V1(y2)} & r_{V2(y2)} & r_{V3(y2)} & r_{V4(y2)} & r_{V5(y2)} \\
    \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
    r_{ym} & r_{V1(ym)} & r_{V2(ym)} & r_{V3(ym)} & r_{V4(ym)} & r_{V5(ym)} 
\end{bmatrix}
\]  

(7)

where \( m \) is the number of the index of \( C_y \). \( r_{ym} \) represents the membership of \( D_{ik} \) belonging to \( V_1, V_2, V_3, V_4, V_5 \) rank.

4.5. Obtaining the comprehensive evaluation vector
Comprehensive evaluation vector can be obtained by synthesizing the judgment matrix with the weight matrix using a suitable operator.

\[
Q = P \circ R
\]  

(8)

where \( Q \) is the comprehensive evaluation vector, \( P \) is the weight matrix, \( R \) is the judgment matrix. \( \circ \) is a weighted averaging operator.

Finally, on the basis of maximum membership degree principle, the evaluation grade of the evaluated object can be determined.

5. Case study

5.1. Evaluation object
This data center built in 2012 has an area of 205m². It has 18 switching equipments, 66 servers and 6 dedicated air conditioners, a dedicated electricity meter, efficient UPS system and video surveillance system. The building layout and equipment configuration reflect energy saving obviously. The data center also applied air flow organization optimization, air-conditioning inverter technology, high voltage DC power supply and other energy saving technology.

According to the actual situation of this data center, the indexes scores given by experts are shown in Table 4.
Table 4  Indexes scores of a data center.

| Name                                      | Scores | Name                                      | Scores |
|-------------------------------------------|--------|-------------------------------------------|--------|
| Power usage effectiveness (PUE)           | 56.8   | Power system energy saving technology     | 70     |
| Data center environment security          | 100    | Energy saving technology of air conditioning system | 80     |
| Communication network security            | 81     | Other equipment energy saving technology   | 0      |
| Location in layout                       | 65     | Green Building Technology                  | 50     |
| Heat insulation design of building envelope | 55   | New energy technology                      | 0      |
| Seal of building envelope                | 100    | Statistical basis                          | 70     |
| Communication equipment selection         | 100    | Organization construction and operation    | 0      |
| Air conditioning equipment selection      | 100    | Specification establishment and Implementation | 60     |
| Power equipment selection                 | 60     | Green energy saving assessment             | 0      |
| Other equipment selection                 | 50     | Improvement and promotion                  | 0      |
| Communication system energy saving technology | 0     |                                          |        |

5.2. Calculation of comprehensive evaluation matrix \( R_{ij} \)

After calculating the membership by indexes scores in Table 4, comprehensive evaluation relationship matrix can be obtained as follows:

\[
R_{11} = \begin{bmatrix}
0.1944 & 0.2133 & 0.2160 & 0.2020 & 0.1743 \\
0.2667 & 0.2437 & 0.2077 & 0.1634 & 0.1186 \\
0.2325 & 0.2318 & 0.2131 & 0.1809 & 0.1417 \\
0.2070 & 0.2198 & 0.2154 & 0.1949 & 0.1628 \\
0.1917 & 0.2118 & 0.2161 & 0.2035 & 0.1769 \\
\end{bmatrix}
\]

\[
R_{12} = \begin{bmatrix}
0.2667 & 0.2437 & 0.2077 & 0.1634 & 0.1186 \\
0.2667 & 0.2437 & 0.2077 & 0.1634 & 0.1186 \\
0.2667 & 0.2437 & 0.2077 & 0.1634 & 0.1186 \\
0.1993 & 0.2158 & 0.2158 & 0.1993 & 0.1698 \\
0.1842 & 0.2077 & 0.2162 & 0.2077 & 0.1842 \\
\end{bmatrix}
\]

\[
R_{21} = \begin{bmatrix}
0.1944 & 0.2133 & 0.2160 & 0.2020 & 0.1743 \\
0.2667 & 0.2437 & 0.2077 & 0.1634 & 0.1186 \\
0.2325 & 0.2318 & 0.2131 & 0.1809 & 0.1417 \\
0.2070 & 0.2198 & 0.2154 & 0.1949 & 0.1628 \\
0.1917 & 0.2118 & 0.2161 & 0.2035 & 0.1769 \\
\end{bmatrix}
\]

\[
R_{22} = \begin{bmatrix}
0.1944 & 0.2133 & 0.2160 & 0.2020 & 0.1743 \\
0.2667 & 0.2437 & 0.2077 & 0.1634 & 0.1186 \\
0.2667 & 0.2437 & 0.2077 & 0.1634 & 0.1186 \\
0.1993 & 0.2158 & 0.2158 & 0.1993 & 0.1698 \\
0.1842 & 0.2077 & 0.2162 & 0.2077 & 0.1842 \\
\end{bmatrix}
\]
5.3. Determination of evaluation vector of $C_{ij}$

The evaluation vectors of $C_{ij}$ can be obtained as follows by $Q_y = P_y \circ R_y$:

$$Q_{11} = [0.1944, 0.2133, 0.2160, 0.2020, 0.1743]$$

$$Q_{12} = [0.2457, 0.2364, 0.2110, 0.1741, 0.1328]$$

$$Q_{21} = [0.2203, 0.2244, 0.2131, 0.1881, 0.1541]$$

$$Q_{22} = [0.2486, 0.2362, 0.2098, 0.1730, 0.1325]$$

$$Q_{23} = [0.1868, 0.2053, 0.2120, 0.2061, 0.1897]$$

$$Q_{24} = [0.1520, 0.1849, 0.2108, 0.2253, 0.2270]$$

5.4. Determination of evaluation vector of $B_i$

The evaluation vectors of $B_i$ can be obtained by $Q_y$ as follows:

$$Q_1 = [0.2034, 0.2174, 0.2151, 0.1971, 0.1670]$$

$$Q_2 = [0.1881, 0.2052, 0.2114, 0.2056, 0.1897]$$

5.5. Determination of evaluation vector of $A$

The evaluation vectors of $A$ can be obtained by $Q_i$ as follows:

$$Q = [0.1934, 0.2093, 0.2127, 0.2027, 0.1820]$$

According to the principle of maximum membership degree, the energy saving grade of this data center is moderate.

6. Conclusions

This paper established an energy saving system evaluation model of China’s data centers on the basis of analytical hierarchy process and fuzzy comprehensive evaluation method. The effectiveness of the index system and the operability of the fuzzy comprehensive evaluation model were proved by a case study. This model is practical in energy saving system evaluation of different data centers. This study gives some references for energy saving construction of data centers in China.
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