Evaluation Index System for Green Building of China Based on Entropy Value Method and Analytic Hierarchy Process (AHP)

Shilin Qu, Jiaguo Hu, and Qian Yu
School of Mechanical Engineering, University of Science and Technology Beijing, Beijing, China
Email: q.shilin@163.com

***Abstract*—In order to meet the conflicting demands of providing energy and scarce resource, many researchers are dedicate themselves to developing renewable energy combined with fossil energy resource with effective method. Evaluation index system is playing an important role to evaluate those measures. The paper's aim is to propose a perfect evaluation index system which is suitable china's available energy situation. Towards this end, the following were done: review the development of green building evaluation system research status; Providing a novel green building evaluation system; Using entropy value method and the analytic hierarchy process (AHP) to determine the first and second weight indicators and form four performance overall rating. This conclusion is validated through a practice case. The result shows that the two methods is feasible and effective and the now evaluation system is scientific and suitable the china's current energy situation.**

***Index Terms*—AHP, entropy value method, green building, evaluation system**

I. Introduction

Due to energy and environment problems become serious increasingly in China, green building in line with the concept of sustainable development has become an inevitable trend. Therefore, it is an important to establish a perfect green building evaluation system suiting our country's present situation.

There are several existing assessment systems already, such as LEED, BREEAM, CASBEE etc., which are relatively representative. These evaluation systems are different from each other in the indicator setting, weight division and evaluation form, but all of them have been in domestic application for many years, and has obtained worldwide approved. China current evaluation system of green building named "Evaluation Standard for Green Building" (GB/T 50378-2006) is playing a role in guiding the green building design, construction and operation [1]-[4].

Every evaluation system has its own characteristics and limitations at the same time. For example, LEED and China green building evaluation index have simple structure, and easy to operate, but evaluation indexes are cursory, the simply quantitative which may result in unreasonable evaluation results.

General speaking that BREEAM is relatively comprehensive, however its aims is not to focus on the specific situation of developing country. Evaluation items of GB Tool and CASBEE are so complex that it is not easy to operate. What's more, besides GB Tool, all other evaluation systems don't considerate the economic analyses [5].

According to china's energy consumption situation, this article put forward a new green building assessment method based on the entropy value method and the Analytic Hierarchy Process (AHP).

II. Mathematical Model

A. Entropy Value Method

Entropy is a concept from thermodynamics. In philosophy and statistical physics, it is interpreted as the confusion and disorder degree brought by the physical system. Information theory argues that it is the uncertainty degree of the information source's state. In the comprehensive evaluation, it is very natural to obtain the order degree and utility value of system information with the information entropy evaluation. For information system entropy function form of the statistical physics should be consistent.

Using entropy determining weight method to analyze the weight of each index is based on the concept and properties of entropy, as well as the relative importance degree uncertainty of each index. Supposing that we have obtained the initial data matrix $X = \{x_{ij}\}_{m\times n}$ of n evaluation indexes of m samples, because the dimensional, order of magnitude and quality orientation of each index are different, the initial data should be done dimensionless processing. The processing method is chosen according to the actual characteristics and properties of the sample.

The standardized matrix after the dimensionless processing is $Y = \{y_{ij}\}_{m\times n}$ .Among them:

$$y_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} (0 \le y_{ij} \le 1) \quad (1)$$

The information entropy value of j indicators is:

Manuscript received July 1, 2015; revised October 8, 2015.

doi: 10.18178/ijscer.4.4.378-381

$$e_j = -k\sum_{i=1}^{m} y_{i,j} \ln y_{i,j} \quad (2)$$

In (2), constant k is related to the sample number m. For a system whose information is completely disordered, the order degree is zero and the entropy value reach the largest value, e equal 1. If m samples are in a fully disordered distribution status, $y_{ij} = 1/m$, then:

$$e = -k\sum_{i=1}^{m}\frac{1}{m}\ln\frac{1}{m} = k\sum_{i=1}^{m}\frac{1}{m}\ln m = k\ln m = 1 \quad (3)$$

So: $k = (\ln m)^{-1} \qquad 0 \le e \le 1$ (4)

As the information entropy ej can be used to measure the utility value of the j index information (index data), when completely disordered, ej = 1. At this moment, the utility value of the ej information is zero for a comprehensive evaluation . Therefore, the information utility value of an index depends on the difference between information entropy index ej and 1.

$$d_j = 1 - e_j \quad (5)$$

The higher the value coefficient is, the greater importance to the evaluation (or the greater contribution to the results of the evaluation) is. So the weight of j index can be calculated by the following equation:

$$W_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \quad (6)$$

B. *Analytic Hierarchy Process (AHP)*

The hierarchical structure with target, sub-goal and constraint condition is the basic principle of AHP to realize evaluation. The following three steps of AHP are firstly determine judgment matrix by using pair wise comparison methods, then treat feature vector component corresponding to the largest eigenvalue of judgment matrix as the corresponding coefficient, finally achievement the weight of each [6].

TABLE I. JUDGING MATRIX OF AHP

A	B1	B2	……	Bn
B1	b11	b12	……	b1n
B2	b21	b22	…….	……
…….	……	…….	……	……
Bn	bn1	bn2	……	bnn

The value of judgment matrix element reflects people's recognition of the relative importance of index to target. For example, if we make elements A of a certain level as the criterion, then compare the importance of all relevant elements which are relative to A element and in the lower level such as Bi and Bj, finally we get multiple comparison judgment matrix, shows on Table I, among them, bij＞0，as i≠j bji=1/bij，as i=j, bii=1.

The assignment of matrix elements is usually using the 9 standard degree method. Specific meaning of 1-9 scale method is shown in Table II.

TABLE II. MEANING OF ANALYTIC HIERARCHY PROCESS (AHP) 1-9 SCALE

C_{ij}	Meaning interpretation	C_{ij}	Meaning interpretation
1	Two elements I and j are equally important	1	Two elements I and j are equally important
2	Between 1 and 3	1/2	Between 1 and 1/3
3	Element I is slightly important than element j	1/3	Element I is slightly not important than element j
4	Between 1 and 3	1/4	Between 1/3 and 1/5
5	Element I is obviously important than element j	1/5	Element I is obviously not important than element j
6	Between 5 and 7	1/6	Between 1/5 and 1/7
7	Element I is strongly important than element j	1/7	Element I is strongly not important than element j
8	Between 7 and 9	1/8	Between 1/7 and 1/9
9	Element I is extremely important than element j	1/9	Element I is extremely not important than element j

According to the matrix theory, eigenvector corresponding to the biggest eigenvalue of the judgment matrix is the weight value.

If we take the weight vector $w = [w_1, w_2, \cdots, w_n]^T$, then get:

$$Aw = \lambda w \quad (7)$$

λ is the biggest positive eigenvalue of matrix A, and W is the characteristic vector of A corresponding to the λ.

In practice, the judgment matrix is required to meet the consistency, so the consistency check should be undertaken. Steps of consistency check are as follows:

(1) Calculation consistency index CI

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad (8)$$

When CI equal 0, the judgment matrix has complete consistency; on the other hand, the greater CI is, the worse the consistency of judgment matrix is.

(2) Determining the corresponding average random consistency index

Table III illustrates the average random consistency index RI according to the different order numbers of the judgment matrix.

TABLE III. THE AVERAGE RANDOM CONSISTENCY INDEX RI

order	1	2	3	4	5	6	7	8
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41
order	9	10	11	12	13	14	15	
RI	1.45	1.49	1.52	1.54	1.56	1.58	1.59	

(3) Calculation of consistency ratio CR and judgment. We definite CR as following equation:

$$CR = \frac{CI}{RI} \quad (9)$$

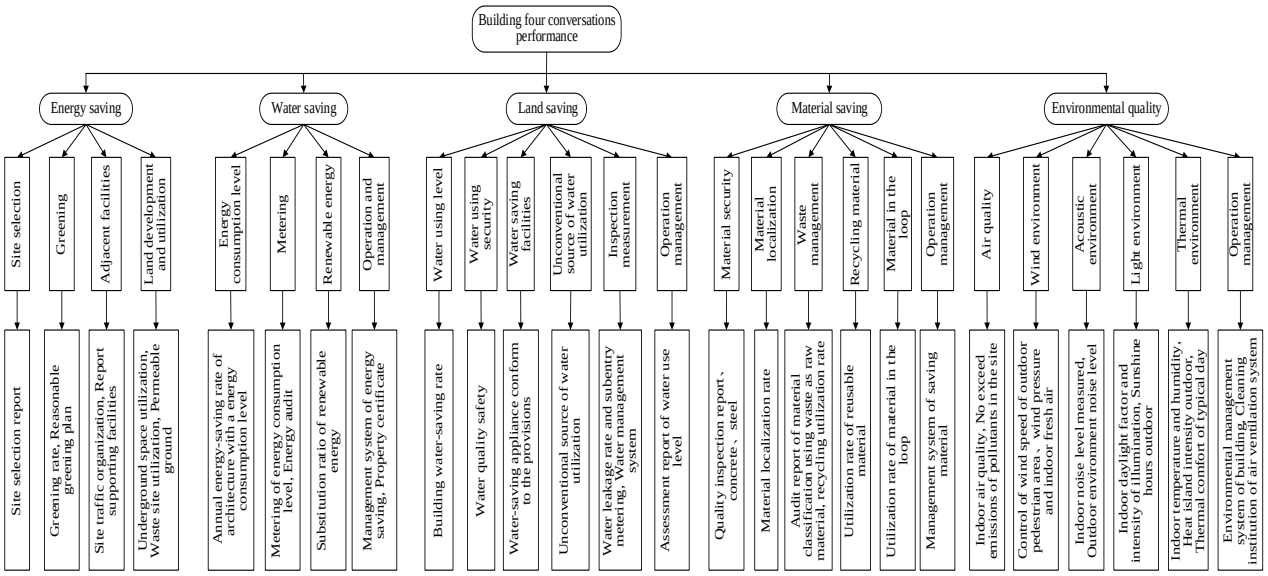

Figure 1. Four conversations performance evaluation index system

When CR < 0.1, we consider the consistency of judgment matrix is acceptable, otherwise, when CR≥0.1, we need to adjust the judgment matrix until satisfy.

III. Building up Four Conversations Performance Evaluation Index System

Combined with China actual situation of green building assessment, this study integrates representative key index, uses comprehensive indicator to reflect building green performance, constructs the evaluation system with the core of " four conversations performance " (as shown in Fig. 1). Its main characteristics are shown as follows:

1) Highlight the "four conversations", emphasize the restriction relationship between "four conversations" and environmental quality.

2) Use quantitative comprehensive assessment index, the maneuverability is strong.

3) Find out problems in time, explore four conversations potential.

4) Combine systematicness and flexibility, multi-objective and multi-level, clear thinking, clear purpose.

IV. Weight Analysis

A. First Level Index Weight of Entropy Value Method

Determining the weight of the index with entropy value method is based on the degree order difference of information contained in index, namely information utility value. So it is a kind of objective weighting method.

This research uses our country's green standard and LEED - EB as the sample data, calculates the weight of the first level index (four conversations and an environmental protection)of four conversations performance system. The specific calculation process is as follows:

(1) Collection and arrangement of the original data

Select china's green standard and LEED - EB as calculation sample. Setting up the initial evaluation matrix:

$$X = \{x_{ij}\}_{2\times 5} \qquad X = \begin{Bmatrix} 0.118 & 0.294 & 0.176 & 0.176 & 0.235 \\ 0.26 & 0.35 & 0.14 & 0.1 & 0.15 \end{Bmatrix}$$

(2) The standardization of data

The standardization of data, and achieving the proportion of matrix:

From (1), we can obtain a result:

$$Y = \begin{Bmatrix} 0.312 & 0.457 & 0.558 & 0.638 & 0.611 \\ 0.688 & 0.543 & 0.442 & 0.362 & 0.389 \end{Bmatrix}$$

(3) Calculation of information index entropy and information utility value

Based on the proportion matrix, we can get information entropy value e and information utility value d, and obtain the weight value.

From (4), k=-1/ln2, take into the (2), get:

$$E = \{0.895 \quad 0.995 \quad 0.990 \quad 0.944 \quad 0.964\}$$

From (2)-(5), get:

$$D = \{0.105 \quad 0.005 \quad 0.010 \quad 0.056 \quad 0.036\}$$

From (6), get index weigh vector:

$$W = \{w_1 \quad w_2 \quad w_3 \quad w_4 \quad w_5\}$$
$$= \{0.187 \quad 0.208 \quad 0.207 \quad 0.197 \quad 0.201\}$$

The above matrix shows that weights of land saving, energy efficiency, water conservation, material saving and environmental quality were 0.187, 0.208, 0.207, 0.201, 0.197 and 0.201 respectively.

The advantage of solving the weight through entropy value method is: reflecting utility value of information entropy, the calculation results is credible, the adaptive function is strong. But it lacks of the horizontal comparison between each index, affected by the fuzzy random, need sample data, the application is restricted. Here we only select two typical samples to calculate, and the adaptability of the sample need to research further, the credibility of the results obviously reduce, therefore we only treat it as a tentative attempt and providing a kind of

thought for the weight calculation of green building evaluation system.

B. Index Weight of AHP

The basic data of AHP is gained through effective questionnaire. Some questionnaires of index weight of green building evaluation system were designed for this study, the objects invited to do the questionnaire are research specialists engaged in the related work of green building. We sent out a total of 42 questionnaires, feedback 38 questionnaires, and all of them are effective.

The weight calculation is undertaken with the hierarchy analysis software yaahp (v0.6.0), yaahp (Yet Another AHP) is a calculation software of analytic hierarchy process (AHP), it provides convenient hierarchical model structure、entry of judgment matrix data, calculation of sorting weight and deriving of calculating data and other functions, yaahp also offers a variety of practical miscellaneous functions, such as consistency modification of judgment matrix, completion of incomplete matrix, group decision making and so on, we can deal with practical problems better if reasonably make use of them.

V. Case Studying

The green building evaluation index system consists of five indexes and the total score of each index is 100 points.

The comprehensive score for the evaluated project with weighted sum method are calculated to be:

$$G = w_1 * L + w_2 * E + w_3 * W + w_4 * M + w_5 * Q \quad (10)$$

Among them, w1 to w5 are the weights of 5 kinds of the first level index. L, E, W, M and Q are respectively the scores of five indexes in the first level.

$$\begin{aligned} L &= w_{L1} * L_1 + w_{L2} * L_2 + w_{L3} * L_3 + w_{L4} * L_4 \\ E &= w_{E1} * E_1 + w_{E2} * E_2 + w_{E3} * E_3 + w_{E4} * E_4 \\ W &= w_{W1} * W_1 + w_{W2} * W_2 + w_{W3} * W_3 + w_{W4} * W_4 + w_{W5} * W_5 + w_{W6} * W_6 \\ M &= w_{M1} * M_1 + w_{M2} * M_2 + w_{M3} * M_3 + w_{M4} * M_4 + w_{M5} * M_5 + w_{M6} * M_6 \\ M &= w_{Q1} * Q_1 + w_{Q2} * Q_2 + w_{Q3} * Q_3 + w_{Q4} * Q_4 + w_{Q5} * Q_5 + w_{Q6} * Q_6 \end{aligned} \quad (11)$$

In the formula above, wL1~ wL4, wE1~ wE4, wW1~ wW6, wM1~ wM6, wQ1~ wQ6 represent each secondary index weight respectively, and as to the specific numerical.

Taking an office building in Beijing as example, which obtained the three-star certification rewarded according to China's green building evaluation standard, we evaluate the building with our evaluation system. Total construction land area is 22519 square meters with 200838 square meters building area. It has 4 floors underground and 22 floors above ground.

We can get the score is 90.184, it is a perfect score. The result matches China's green building evaluation standard, which proves that the four conversations performance evaluation index system of the green building built by this paper is accurate and feasible.

Acknowledgements

This research has been supported by the National Science & Technology Pillar Program during the 12th Five-year Plan Period (2012BAJ06B06, 2014BAJ01B03) and Beijing Higher Education Young Elite Teacher Project (YETP0370). The authors also wish to express their gratitude to the authors of the article that cited in this paper.

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Shilin Qu was born in Harbin in August, 1978. In 1999, she earned Bachelor Degree in school of municipal and environmental engineering, Harbin institute of technology, Harbin, China. In 2001 she earned Master Degree and then in 2004 she achieved Doctoral Degree in the same university. Her major research direction is the use of renewable energy in the architecture.

Since 2004, she has been working in the University of Science & Technology Beijing. Since 2001, she has been the Dean of building environment and equipment engineering department. She's published many articles, including Testing and Analysis of Thermal Performance of Ground Source Heat Pump System, BP neural network for the prediction of urban building energy consumption based on Matlab and its application, etc. Her current and previous research interest is building system optimization and evaluation.