Fuzzy Comprehensive Evaluation Model and Influence Factors Analysis on Comprehensive Performance of Green Buildings

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Abstract: A **g**reen building involves complex system engineering including energy efficiency and energy utilization, water-saving and water utilization, material-saving and material utilization, and land-saving and indoor environment quality and operation management. In order to solve problems of subjectivity, uncertainty and impossibility of quantitative analysis when evaluating green building, this study establishes a multi-level fuzzy evaluation model by means of fuzzy mathematics method to analyze the comprehensive performance of green building according to the index system of "Evaluation Standard for Green Building". Combined with the technique scheme of the first China green building demonstration project, the result proves to be in accordance with the pre-evaluation of experts. It shows that the fuzzy comprehensive evaluation method is reasonable and feasible to evaluate the comprehensive performance of green building. The evaluation result is the same as the pre-evaluation result. Factors with high weights have larger effects on the results. This proves that the guideline should be the first reference mode in the future engineering practice so as to realize optimization of green building performance.

Key words: Green building; Comprehensive performance; Fuzzy comprehensive evaluation, Influence factors

1. INTRODUCTION

Green building is the complex system engineering including energy efficiency and energy utilization, water-saving and water utilization, material-saving and material utilization, land-saving and indoor environment quality and operation management. China formulates "Technology Guideline of Green Building", which offers the technique support and criterion for constructing green building. At the same time, it is obvious and important problem how to appraise green building performance. At present, there are many evaluation systems of green building, for instance, American LEED green building evaluation system, German bio-guideline LNB, British BREEM system, Australian building environment system NABERS, Canada GBTool, Norway Eco Profile, French ESCALE and so on [1]. But these are not fit for the practical conditions of green building in China. Therefore, Chinese government formulates and implements "Evaluation Standard for Green Building" on 1st June, 2006. It not only has directive role to construct green building but also is good for standardizing and steering green building market development. Whereas, the different rank of green building is a fuzzy concept and difficult to define, which includes the evaluation result of green building of one star, two star and three stars [2]. This study proposes fuzzy comprehensive evaluation method to evaluate green building performance in order to validate consistency degree to "Standard for

Evaluation of Green Building".

Fuzzy comprehensive evaluation quantifies the fuzzy indexes of evaluation objects through establishing grade fuzzy subset, and then utilizes fuzzy variable principle to integrate each index so as to better solve the fuzzy problem such as clear characteristics of different attributes, fuzzy characteristics of evaluation experts understanding and so on. It has gotten better evaluation effect in the following research fields, such as customer satisfaction degree evaluation, comprehensive technician evaluation, company ability evaluation, human capital evaluation and so on [3]. During the course of evaluating green building, the result of green building performance is also fuzzy concept. And there are many fuzzy influence factors. Therefore, this study evaluates green building with fuzzy comprehensive evaluation method.

This study adopts the research methods combining positive and theoretical method. On basis of establishing fuzzy comprehensive model, confirm evaluation index system of green building performance, calculate example of green building demonstration, and finally draw conclusions.

2. MODEL OF FUZZY COMPREHENSIVE EVALUATION

Fuzzy comprehensive evaluation model involves four factors. (1) Factor set *U*; (2) Comment set *V*; (3) Evaluation matrix of single factor *R*; (4) weight distribution vector *A* [4]. Secondary fuzzy comprehensive evaluation is used in fuzzy evaluation of green building performance. The concrete model factors including the followings.

(1) Establish factor set $U = \{U_1, U_2, \cdots\cdots U_6\}$ = {land-saving and indoor environment quality, energy efficiency and energy utilization, water-saving and water utilization, material-saving and material utilization, operation management}. Each factor (U_i) includes secondary factor set $U_i = \{u_{i1}, u_{i2}, \cdots\cdots u_{in}\}$ $i = 1,2,\cdots 6$. n equals to the amount that different factor set includes contents.

(2) Establish the weight set of each factor in U $A = (A_1, A_2, \cdots\cdots A_6)$ $A_i > 0, \sum_{i=1}^{6} A_i = 1$. The weight set of $u_i (i = 1,2,\cdots\cdots 6)$ is $A_i = (a_1, a_2, \cdots\cdots a_n)$ $a_i > 0, \sum_{i=1}^{n} a_i = 1$. n also equals to the amount that different factor set includes contents.

(3) On the assumption that the comment set of *U* is $V = \{V_1, V_2, V_3\}$ = {one star, two stars, three stars}.

(4) Evaluate each single factor in *U* set. The evaluation matrix $R_i = (r_{ij})_{n\times m}$ can be gotten, here, $r_{ij} (i = 1,2,\cdots\cdots 6)$ represents the membership degree of j factors to comment V_i. And the next layer matrix can be gotten as the same method.

(5) Through evaluate *U*, it can get the following matrix that is the evaluation result of all factors in *U* set [5].

$$B = A \bullet R = A \bullet \begin{bmatrix} R_1 \\ R_2 \\ \vdots \\ R_6 \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{61} & r_{62} & \cdots & r_{6n} \end{bmatrix}$$

3. EVALUATION INDEX SYSTEM OF GREEN BUILDING PERFROMENCE

According to "Evaluation Standard for Green Building" and "Technical standard for performance assessment of residential buildings", the green building performance can be express by the following indexes. And these indexes can be divided into two layers. The concrete contents include followings.

3.1 Land-saving and Outdoor Environment Quality

(1) Parking proportion under ground. The total parking proportion under ground or half under ground is more than 60 percent.

(2) Plot ratio. Rationally utilize land resource and plot ratio should accord with planning condition.

(3) Architecture design. It can guarantee the sunlight, day lighting and ventilation environment.

(4) New type wall material. Adopt new type wall

material instead of clay brick.

(5) Land-saving measure. Adopt new equipments, new techniques and new materials in order to reduce the construction area occupied by public establishment.

(6) Public building under ground. Part public buildings (service, entertainment and environment protection) should fully utilize the space under ground.

(7) Land utilization. Utilize wild land, sloping field and other unsuited infield as much as possible. And the afforestation rate in living area is not less that 30 percent.

3.2 Energy Efficiency and Energy Utilization

(1) Architecture design. It includes building orientation, shape coefficient, ratio of glazing to floor area, external shading measures and renewable energy utilization.

(2) Envelop structure. Guarantee the rational heat transfer coefficient of external window, external wall and roof.

(3) HVAC. Adopt the energy-using distribution technique, put apart the rational place in advance and control temperature at any time.

(4) Lighting system. Adopt energy efficient lighting products.

3.3 Water-saving and Water Utilization

(1) Reclaim water utilization. The building community that construction area is over 50,000 m^2 should equip reclaimed water facilities or connect with urban water system. The building community that construction area is under 50,000 m^2 or the water resource amount or reclaimed amount is too small (less than 50m^3/d) should design and equip water pipeline systems and other water facilities.

(2) Rain water utilization. Adopt measures reclaiming or back-infiltrating rain water.

(3) Water-saving instruments and pipelines. Utilize sanitary ware that capacity is less than 6L and equip two drive selections. Utilize water-saving faucet. And watering pipeline and part adopts material that is not easy escaping.

(4) Water-saving in public buildings. Toilet equipment, shower apparatus, sanitary ware and other public facilities all adopt water-saving equipments with time-lapse and automatic taps or valves.

(5) Landscape water utilization. Greenbelt, forest and flowers use drip-irrigate, micro-spray and other water-saving irrigation modes. Don't use tap water as supplementary water of landscape water utilization.

3.4 Material-saving and Material Utilization

(1) Renewable energy utilization.

(2) New techniques of architecture design and construction. Adopt three to four new types of techniques.

(3) New material-saving measures. Adopt new techniques and technologies of material-saving [6].

(4) Material reclaiming ratio. Utilize certain proportion renewable glass, concrete and wooden in order to reclaim construction material [7].

3.5 Indoor Environment Quality

(1) Indoor sunlight and natural ventilation. More than one living space in each building can satisfy the requirement of standard of sunlight and natural ventilation.

(2) Sound insulation and noise reduction measures. Adopt effective sound insulation and noise reduction measures in building envelop.

(3) Rational ratio of glazing to floor area. It can guarantee the natural ventilation.

(4) External and internal shading measures. Prevent sun radiation in summer directly into indoors.

3.6 Operation Management

(1) Garbage classification and biologic treatment. Establish garbage management system to effectively control garbage logistics. And collect waster according to different types to prevent throw off garbage at random and secondary pollution.

(2) Intellectualized system. It has good and proper orientation and reaches the basic condition of safety protection subsystem, management and establishment monitoring subsystem and information network subsystem.

Tab. 1 Table of fuzzy comprehensive evaluation of green building performance

Factor set 1	Weight 1	Factor set 2	Weight 2	Fuzzy evaluation matrix		
				One star	Two stars	Three stars
Land-saving and outdoor environment	0.1	Parking proportion under ground	0.2	0.15	0.25	0.6
		Plot ratio	0.125	0.2	0.3	0.5
		Architecture design	0.175	0.2	0.3	0.5
		New type wall material	0.2	0.15	0.25	0.6
		Land-saving measure	0.125	0.25	0.3	0.55
		Public building under ground	0.125	0.1	0.3	0.6
Energy efficient and energy utilization	0.5	Land utilization	0.05	0.1	0.4	0.5
		Architecture design	0.35	0.1	0.2	0.7
		Envelop structure	0.35	0.1	0.2	0.7
		HVAC	0.2	0.15	0.25	0.6
		Lighting system	0.1	0.1	0.25	0.65
Water-saving and water utilization	0.2	Water utilization	0.3	0.3	0.3	0.4
		Rain water utilization	0.15	0.2	0.4	0.4
		Water-saving instrument and pipeline	0.3	0.1	0.2	0.7
		Water-saving in public building	0.15	0.25	0.35	0.4
		Landscape water utilization	0.1	0.15	0.3	0.55
Material-saving and material utilization	0.1	Renewable energy utilization	0.15	0.35	0.25	0.4
		New techniques of architecture design and construction	0.5	0.2	0.3	0.5
		New material-saving measures	0.1	0.3	0.1	0.6
		Material reclaiming ratio	0.25	0.15	0.35	0.5
Indoor environment quality	0.05	Indoor sunlight and natural ventilation	0.3	0.3	0.2	0.5
		Sound insulation and noise reduction measures	0.2	0.3	0.2	0.5
		Rational the square proportion window to floor	0.3	0.25	0.35	0.4
		Inside and outside shading measures	0.2	0.2	0.3	0.5
Operation management	0.05	Garbage classification and biologic treatment	0.3	0.1	0.3	0.6
		Intellectualized system	0.3	0.2	0.25	0.55
		All kinds of management system	0.4	0.2	0.3	0.5

(3) All kinds of management system. Establish and implement energy efficient, water-saving, material-saving and virescence management system [8].

4. EVALUATION MODEL OF GREEN BUILDING PERFORMANCE

According to above mathematic model and index system, one residential building demonstration project is selected as example to utilize fuzzy comprehensive evaluation method to appraise again. During the course of TOR and feasible research stage, the evaluation result is green building of three stars in advance. The following description is evaluation process by fuzzy comprehensive evaluation method. After through Delphi method, each expert give marks of different items and the following evaluation matrixes in Tab. 1 can be gotten.

The weight matrix of primary index is $A=\begin{bmatrix}0.1 & 0.5 & 0.2 & 0.1 & 0.05 & 0.05\end{bmatrix}$ .The weight matrix of secondary index respectively is followings.

$A_1=\begin{bmatrix}0.2 & 0.125 & 0.175 & 0.2 & 0.125 & 0.125 & 0.05\end{bmatrix}$

$A_2=\begin{bmatrix}0.35 & 0.35 & 0.2 & 0.1\end{bmatrix}$

$A_3=\begin{bmatrix}0.3 & 0.15 & 0.3 & 0.15 & 0.1\end{bmatrix}$

$A_4=\begin{bmatrix}0.15 & 0.5 & 0.1 & 0.25\end{bmatrix}$

$A_5=\begin{bmatrix}0.3 & 0.2 & 0.3 & 0.2\end{bmatrix}$

$A_6=\begin{bmatrix}0.3 & 0.3 & 0.4\end{bmatrix}$.

The secondary fuzzy comprehensive evaluation matrixes are followings.

$$R_1=\begin{bmatrix}0.15 & 0.25 & 0.6\\ 0.2 & 0.3 & 0.5\\ 0.2 & 0.3 & 0.5\\ 0.15 & 0.25 & 0.6\\ 0.25 & 0.3 & 0.55\\ 0.1 & 0.3 & 0.6\\ 0.1 & 0.4 & 0.5\end{bmatrix} \quad R_2=\begin{bmatrix}0.1 & 0.2 & 0.7\\ 0.1 & 0.2 & 0.7\\ 0.15 & 0.25 & 0.6\\ 0.1 & 0.25 & 0.65\end{bmatrix}$$

$$R_3=\begin{bmatrix}0.3 & 0.3 & 0.4\\ 0.2 & 0.4 & 0.4\\ 0.1 & 0.2 & 0.7\\ 0.25 & 0.35 & 0.4\\ 0.15 & 0.3 & 0.55\end{bmatrix} \quad R_4=\begin{bmatrix}0.35 & 0.25 & 0.4\\ 0.2 & 0.3 & 0.5\\ 0.3 & 0.1 & 0.6\\ 0.15 & 0.35 & 0.5\end{bmatrix}$$

$$R_5=\begin{bmatrix}0.3 & 0.2 & 0.5\\ 0.3 & 0.2 & 0.5\\ 0.25 & 0.35 & 0.4\\ 0.2 & 0.3 & 0.5\end{bmatrix} \quad R_6=\begin{bmatrix}0.1 & 0.3 & 0.6\\ 0.2 & 0.25 & 0.55\\ 0.2 & 0.3 & 0.5\end{bmatrix}$$

According to $B_i=A_i \bullet R_i$, comprehensive evaluation vector of secondary indexes to their upper indexes can be calculated.

$B_1=\begin{bmatrix}0.16875 & 0.285 & 0.54625\end{bmatrix}$

$B_2=\begin{bmatrix}0.11 & 0.215 & 0.675\end{bmatrix}$

$B_3=\begin{bmatrix}0.2025 & 0.2925 & 0.505\end{bmatrix}$

$B_4=\begin{bmatrix}0.22 & 0.285 & 0.495\end{bmatrix}$

$B_5=\begin{bmatrix}0.235 & 0.265 & 0.4\end{bmatrix}$

$B_6=\begin{bmatrix}0.17 & 0.255 & 0.545\end{bmatrix}$.

Fuzzy comprehensive evaluation matrix of primary indexes can be gotten as followings.

$$R=\begin{bmatrix}B_1\\ B_2\\ B_3\\ B_4\\ B_5\\ B_6\end{bmatrix}=\begin{bmatrix}0.16875 & 0.285 & 0.54625\\ 0.11 & 0.215 & 0.675\\ 0.2025 & 0.2925 & 0.505\\ 0.22 & 0.285 & 0.495\\ 0.235 & 0.265 & 0.4\\ 0.17 & 0.255 & 0.545\end{bmatrix}$$

And evaluation result of primary indexes is $B=A\bullet R=\begin{bmatrix}0.154625 & 0.249 & 0.596375\end{bmatrix}$. Suppose comment set V= {one star, two stars, three stars} $=\begin{bmatrix}1 & 2 & 3\end{bmatrix}$, the comprehensive evaluation mark of green building performance is $T=V\bullet B^{-1}=\begin{bmatrix}1 & 2 & 3\end{bmatrix}\bullet\begin{bmatrix}0.154625\\ 0.249\\ 0.596475\end{bmatrix}=2.44175$.

In general, if the mark in [1, 1.7], the building belongs to green building of one star. If the mark in [1.7, 2.4], the building belongs to green building of three stars. If the mark in [2.4, 3], the building belongs to green building of three stars. To this example, $2.44175\in[2.4,3]$. Therefore, this building reaches to standards of three stars in “Evaluation Standard for Green Building”. And the evaluation result is same to pre-evaluation result.

5. CONCLUSIONS

Through above example evaluation, it can be drawn the following conclusions. (1) Fuzzy comprehensive evaluation method has advantage on evaluating green building for effectively avoiding personnel subjective judgment. After different experts marking to different indexes, the evaluation matrix is easy to be gotten through certain methods. The final evaluation result can be gotten with fixed mathematic model. (2) To this method, the evaluation indexes are the most important influence factors. Therefore, index selection should be confirmed through expert argumentations. (3) Factors with high weight have bigger effect to the evaluation result. Therefore, during the course of construction these factors should be paid more attentions. (4) For the characteristics of fuzzy comprehensive evaluation methods, this study suggests that it can be used before evaluating green building by "Evaluation Standard for Green Building" so as to give guideline to evaluate "innovative reward of green building". (5) It is important guarantee for optimizing green building performance to strengthen paying more attentions to contents of "Evaluation Standard for Green Building" in future practice.

On the other hand, this study only selects a residential building example to evaluate performance by fuzzy comprehensive evaluation method. Whether fit for public building or not needs further to be validated. Therefore, it needs further study in future research.

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