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Construction and application of comprehensive evaluation method on energy conservation of residential buildings

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ABSTRACT

Through establishing scientific evaluation index system for energy conservation of residential buildings and introducing fuzzy mathematics and grey system theory, a more perfect and reasonable comprehensive evaluation method on energy conservation effect of residential buildings was established as more scientific, fair, reasonable and convenient than traditional evaluations, providing theoretical foundations for planning department, design unit, real estate developers and owners in determination of design scheme or selection of residential standards.

KEYWORDS

Residential buildings; Building energy conservation; Fuzzy evaluation; Fuzzy grey comprehensive evaluation.

INTRODUCTION

Currently, new green ecological residential buildings are in the ascendant around the world. As viewed from the market philosophy on sustainable development of residential areas, an irresistible general trend will be shown in rapid development of green ecological residential buildings in China. In case of failing to seize the current opportunity to timely introduce the “ecological idea” into design of residential buildings as well as solve the issues of energy conservation of residential buildings and environmental protection in residential areas, irrecoverable consequences will be caused to the society, economy and environment. Therefore, design of energy-conserving houses as well as research and development of residential energy-conserving technology will not only be an extremely important hot spot issue in current construction industry, but also be a significant symbol of construction technical progress, and a key link for sustainable development of construction industry as well. The main factors affecting the energy conservation of residential buildings was put forward preliminarily in this study, where the fuzzy mathematics and grey system theory were applied to comprehensive evaluation on energy conservation of residential buildings. The evaluation process will be more scientific, fair, reasonable and convenient through establishing a comprehensive evaluation model, providing theoretical foundations for relevant planning department, design unit, real estate developers and a majority of owners in determination on the design scheme for energy conservation of residential buildings and selection on residential standards.

THEORETICAL FOUNDATION FOR EVALUATION METHOD PROPOSING

As the existing comprehensive evaluation model for energy conservation of residential buildings is extremely abstract with a low-availability evaluation information, it cannot play the due role in energy-conserving evaluation of residential buildings. Therefore, there is no effective method available to perform comprehensive evaluation on the design from the aspect of energy-conserving level at the completion of new building design. It is also unavailable to execute effective supervisions on the implementation status of standards. The scientific evaluation method and control means shall be adopted through the planning and design process till the completion of building completely. It will be definitely difficult to achieve the expected energy-conserving effect without scientific and complete evaluation system and target.

Fuzzy mathematics and grey system theory are currently two commonly used uncertainty system research methods, in which the fuzzy mathematics method focuses on the research of “cognitive uncertainty” issues with its research object characterized by “certain connotation, and uncertain extension”, while the grey system theory mainly pays attention to research on the uncertainty issues of “small sample” and “poor information” which cannot be solved by fuzzy mathematics. Different from fuzzy mathematics, grey system theory focuses on the research of “certain extension, and uncertain connotation”. Solo use of fuzzy mathematics will cause information loss, while that of grey system theory will not make full use of fuzziness characteristics of evaluation rules, leading to deviations between evaluation result and actual situation. For the comprehensive evaluation on energy conservation of residential buildings, fuzzy evaluation method will be adopted due to the fuzziness of evaluation criteria. In addition, a certain scale of grey will exist in evaluation information due to the differences in ability and preference for different judges, so that the grey theory[1] is introduced into evaluation. Therefore, aiming at the fuzziness and grey of expert evaluation information on energy-conservation of residential buildings, the grey theory and fuzzy evaluation method were combined to establish a comprehensive evaluation method based on fuzzy grey in this study.

ESTABLISHMENT OF EVALUATION MODEL

There are many complex uncertain factors influencing the energy conservation of residential buildings. The grey correlation analysis was used to determine the weight coefficient of influencing factors and assign a weight coefficient to the index (influencing factor) established by experts. Considering a certain scale of grey in expert evaluation information, the whitenization weight function was established in accordance with the grey evaluation on triangle whitenization weight function. Through the matrix of integrated cluster coefficient obtained by grey cluster theory, the fuzzy membership matrix was constructed. Then, the fuzzy algorithm was applied to evaluating the energy-conserving effect, so as to combine grey theory with fuzzy evaluation method as well as construct a comprehensive evaluation method based on fuzzy grey.

Establishment of evaluation index set

Assuming that the energy-conserving effect (y) of residential buildings is composed of n (n=1, 2, …) first level factors, while each first level factor is composed of several second level factors. If the first level index is assumed to be (y1, y2, K, yi, K yn), then the second level index will be set as ($y_{i1}, y_{i2}, \dots, y_{ii}, \dots y_{ij}$), $i = 1, 2, \dots, m$.

Wight determination of various index factors

As there are many uncertain factors influencing the energy conservation of residential buildings, the experts engaged in energy conservation of residential buildings from local government, design unit, universities and colleges, real estate developer and other departments, enterprises and public institutions shall be invited to assign weight coefficients to the established first and second level indexes. Then, the weight coefficients of indexes will be determined by grey correlation analysis. Assuming that the determined weight vector of first-level factor is $w_1, w_2, \ldots, w_i, \ldots w_n$, then that of the second-level factor will be $w_{i1}, w_{i2}, \ldots, w_{ii}, \ldots w_{ij}, i = 1, 2, \ldots, m$ [2].

Establishment of fuzzy membership matrix with grey cluster theory

(1) Determine evaluation criteria. The evaluation criteria (referring to TABLE 1[3]) can be established, and the influence coefficient refers to the influence degree of index *j* on higher level factors. For example, when the energy-conserving coefficient is 0.1, 0.5 and 0.9, index *j* will have a low, medium and high influence degree on higher level factors respectively.

TABLE 1 : Influence of index on higher level factors

Influence coefficient	Low	Medium	High
Value	0.1~0.3	0.3~0.7	0.7~0.9

(2) Determine evaluation sets. The evaluation sets for energy conservation of residential buildings are determined as low, medium and high with the energy conserving coefficient $\in$(O.1,0.3), [0.3,0.7] and (0.7,O.9) respectively.

(3) Determine sample matrix. Assuming that there are *r* (r=1, 2, 3...) experts evaluating the index layer according to evaluation rules, the evaluation vector of the *j*-th index of factor *i* is obtained as ($y'_{ij1}, y'_{ij2}, \ldots, y'_{ijk}, \ldots, y'_{ijr}$), then the comprehensive evaluation vector of the *j*-th index can be expressed as below:

$$y_{ij} = \left(\sum q \times y'_{ijk}\right)/ r \tag{1}$$

In Equation (1), *q* is the number of *j*-th index of factor i, evaluated as y'_{ijk}. Therefore, the comprehensive evaluation vector of *j*-th index of factor *i* can be expressed as ($y_{i1}, y_{i2}, \ldots, y_{ii}, \ldots y_{ij}$).

(4) Establish the evaluation grey classification. The whitenization weight function is established according to grey evaluation based on triangle whitenization weight function[4], then the whitenization function of *k*-th (k=1, 2, 3) grey classification of *j*-th index is expressed as follows:

$$f_j^k(y) = \left\{ \begin{array}{ll} o & , \quad y \notin \left[y_j^{k-1}, y_j^{k+2}\right] \\ \dfrac{y - y_j^{k-1}}{\lambda_j^k - y_j^{k-1}} & , \quad w \in \left[y_j^{k-1}, \lambda_j^k\right] \\ \dfrac{y_j^{k+2} - y}{y_j^{k+2} - \lambda_j^k} & , \quad w \in \left[\lambda_j^k, y_j^{k+2}\right] \end{array} \right\} \tag{2}$$

In Equation (2), the value domain of *j*-th index is extended to $y_1^0 = 0, y_j^5 = 1$, while $y_j^1, y_j^2, y_j^3, y_j^4$ are taken as the threshold values of three grey classifications with “low energy conservation”, “medium energy conservation” and “high energy conservation”, i.e., $y_j^1 = 0.1, y_j^2 = 0.3, y_j^3 = 0.7, y_j^4 = 0.9$.

λ_j^k is taken as the average value of y_j^k and y_j^{k+1}, i.e.,

$$\lambda_j^1 = \frac{1}{2}(y_j^1 + y_j^2) = \frac{1}{2}(0.1 + 0.3) = 0.2$$

$$\lambda_j^2 = \frac{1}{2}(y_j^2 + y_j^3) = \frac{1}{2}(0.3 + 0.7) = 0.5$$

$$\lambda_j^3 = \frac{1}{2}(y_j^3 + y_j^4) = \frac{1}{2}(0.7 + 0.9) = 0.8$$

Substituting the above specific values into Equation (2), the triangle whitenization weight function of j can be obtained, i.e.,

$$f_j^1(y)=\begin{cases} o & , \quad y\notin[0,0.7] \\ \dfrac{y}{0.2} & , \quad y\in[0,0.2] \\ \dfrac{0.7-y}{0.5} & , \quad y\in[0.2,0.7] \end{cases} \tag{3}$$

$$f_j^2(y)=\begin{cases} 0 & , \quad y\notin[0.1,0.9] \\ \dfrac{y-0.1}{0.4} & , \quad y\in[0.1,0.5] \\ \dfrac{0.9-y}{0.4} & , \quad y\in[0.5,0.9] \end{cases} \tag{4}$$

$$f_j^3(y)=\begin{cases} o & , \quad y\notin[0.3,1] \\ \dfrac{y-0.3}{0.5} & , \quad y\in[0.3,0.8] \\ \dfrac{1-y}{0.2} & , \quad y\in[0.8,1] \end{cases} \tag{5}$$

In the white functions of k-th (k=1, 2, 3…) grey classification of j-th index, Equation (3), (4) and (5) are classified as the whitenization weight functions with low, medium and high energy-conservation respectively.

(5) The fuzzy membership matrix δ_i of configuration i.

The comprehensive cluster coefficient matrix δ_i of configurative object i, i.e., the fuzzy membership matrix δ_i of factor i is shown as below.

$$\delta_i=(\delta_i^k)=\begin{bmatrix} \delta_1^1 & \delta_1^2 & \dots & \delta_1^t \\ \delta_2^1 & \delta_2^2 & \dots & \delta_2^t \\ \dots & \dots & \dots & \dots \\ \delta_n^1 & \delta_n^2 & \dots & \delta_n^t \end{bmatrix} \tag{6}$$

The matrix in Equation (6) refers to the fuzzy membership matrix of j-th index of factor i with (low, medium and high) energy conservation, where δ_i^k is the comprehensive cluster coefficient of k-th grey classification of object i,, $\delta_i^k=\sum_{j=1}^{m} f_j^k(y_{ij})\bullet\xi_j^k$, ξ_j^k is the weight of subclass k of index j.

$$\xi_j^k=\frac{\lambda_j^k}{\sum_{j=1}^{m}\lambda_j^k} \tag{7}$$

Fuzzy evaluation

The following is obtained based on the evaluation of factor i:

$$\vec{V}_i=[d_{i1},d_{i2},d_{i3}]=[w_{i1},w_{i2},\dots,w_{in}]\circ\delta_i \tag{8}$$

where, the operation of "o" shall be weighting operation.

In accordance with $\max_{1\le k\le t}\{\delta_i^k\}=\delta_i^{k*}$, the object i is judged to be grey classification k*, i.e.,

When $D_1=\max\{D_1,D_2,D_3\}$, the project has a low energy-conserving effect; **(9)**

When $D_2 = \max\{D_1, D_2, D_3\}$, the project has a medium energy-conserving effect; **(10)**

When $D_3 = \max\{D_1, D_2, D_3\}$, the project has a high energy-conserving effect; **(11)**

ACTUAL APPLICATION OF FUZZY GREY COMPREHENSIVE EVALUATION METHODS IN THE EVALUATION ON ENERGY CONSERVATION OF RESIDENTIAL BUILDINGS

A certain scale of grey will exist in the evaluation information, due to many complicated factors influencing the energy conservation of residential building, the fuzziness of evaluation criteria and the differences in ability and preference for different judges. Therefore, it will be feasible to establish corresponding energy-conserving indexes and apply the fuzzy grey evaluation method to perform evaluations on energy-conserving effect.

Establish evaluation index sets. The experts are kindly requested to give marks to the energy-conserving coefficients of various indexes within a range of (0,1) according to TABLE 1. Please refer to TABLE 2.

TABLE 2 : Evaluation marks of energy-conserving effect

Main factor	Weight	Sub-factor	Weight	Level		
				Low	Medium	High
Planning & design	0.10	Duration of sunshine	0.60	0.10	0.30	0.60
		Building density	0.20	0.20	0.50	0.30
		Plot ratio	0.20	0.20	0.60	0.20
Architectural design	0.20	Building size	0.20	0.10	0.30	0.60
		Storey height of building	0.10	0.20	0.40	0.40
		The area of housing	0.30	0.50	0.30	0.20
		Room distribution	0.40	0.15	0.50	0.35
Structural design	0.20	Structure type	0.20	0.20	0.40	0.40
		Wall design	0.60	0.10	0.30	0.60
		Roof structure	0.20	0.15	0.35	0.50
Decorative design	0.30	Door & window structure	0.50	0.10	0.20	0.70
		Wall insulation structure	0.35	0.10	0.20	0.70
		Window-wall ratio	0.15	0.60	0.30	0.10
Economic indicator	0.20	Construction cost per square meter	0.70	0.10	0.30	0.60
		Serviceable life	0.30	0.20	0.20	0.60

(2) Determine the weights of various factors. The experts or personnel with equivalent competencies engaged in building energy conservation will be kindly invited to make the judgment and decision on various factors. The weight vector of main factors will be $[w_1, w_2, w_3, w_4, w_5] = [0.10, 0.20, 0.20, 0.30, 0.20]$, and that of sub-factors will be $[w_{11}, w_{12}, w_{13}] = [0.60, 0.20, 0.20]$, $[w_{21}, w_{22}, w_{23}, w_{24}] = [0.20, 0.10, 0.30, 0.40]$, $[w_{31}, w_{32}, w_{33}] = [0.20, 0.60, 0.20]$, $[w_{41}, w_{42}, w_{43}] = [0.50, 0.35, 0.15]$ and $[w_{51}, w_{52}] = [0.70, 0.30]$ respectively.

(3) Calculate and count the grey number as well as construct the fuzzy membership matrix. The grey statistics of each index are calculated by using the above whitenization weight function (3), (4) and (5) corresponding to high, medium and low energy-conservation respectively. The fuzzy membership matrix and the evaluation matrix are obtained to calculate the evaluation results. According to Equation (6), the following can be calculated:

$$\delta_1 = \begin{pmatrix} 0.1 & 0.3 & 0.6 \\ 0.2 & 0.5 & 0.3 \\ 0.2 & 0.6 & 0.2 \end{pmatrix}$$

Similarly, δ_2, δ_3, δ_4, δ_5 can be calculated.

(4) Evaluate the fuzzy comprehensively. The following can be obtained according to Equation (8):

$$\vec{V}_1 = [0.6 \quad 0.2 \quad 0.2] \begin{pmatrix} 0.1 & 0.3 & 0.6 \\ 0.2 & 0.5 & 0.3 \\ 0.2 & 0.6 & 0.2 \end{pmatrix} = [0.14 \quad 0.4 \quad 0.46]$$

Similarly, the following can be calculated:

$$\vec{V}_2 = [0.2 \quad 0.1 \quad 0.3 \quad 0.4] \begin{pmatrix} 0.1 & 0.3 & 0.6 \\ 0.2 & 0.4 & 0.4 \\ 0.5 & 0.3 & 0.2 \\ 0.15 & 0.5 & 0.35 \end{pmatrix} = [0.25 \quad 0.39 \quad 0.36]$$

$$\vec{V}_3 = [0.2 \quad 0.6 \quad 0.2] \begin{pmatrix} 0.2 & 0.4 & 0.4 \\ 0.1 & 0.3 & 0.6 \\ 0.15 & 0.35 & 0.5 \end{pmatrix} = [0.13 \quad 0.33 \quad 0.54]$$

$$\vec{V}_4 = [0.5 \quad 0.35 \quad 0.25] \begin{pmatrix} 0.1 & 0.2 & 0.7 \\ 0.1 & 0.2 & 0.7 \\ 0.6 & 0.3 & 0.1 \end{pmatrix} = [0.17 \quad 0.245 \quad 0.585]$$

$$\vec{V}_5 = [0.7 \quad 0.3] \begin{pmatrix} 0.1 & 0.3 & 0.6 \\ 0.2 & 0.2 & 0.6 \end{pmatrix} = [0.13 \quad 0.27 \quad 0.6]$$

After normalization, the following can be obtained as below:

$$D_1 = 0.1 \times 0.14 + 0.2 \times 0.25 + 0.2 \times 0.13 + 0.3 \times 0.17 + 0.2 \times 0.13 = 0.167$$

$$D_2 = 0.1 \times 0.4 + 0.2 \times 0.39 + 0.2 \times 0.33 + 0.3 \times 0.245 + 0.2 \times 0.27 = 0.3115$$

$$D_3 = 0.1 \times 0.46 + 0.2 \times 0.36 + 0.2 \times 0.54 + 0.3 \times 0.585 + 0.2 \times 0.6 = 0.5215$$

Then, the energy-conserving effects of residential buildings can be determined as high, medium and low according to Equation (9), (10) and (11).

CONCLUSIONS

The newly-established evaluation method on the energy-conserving effect of residential buildings is to introduce the fuzzy grey comprehensive evaluation method with fuzziness and grey combined on a basis of multi-target decision-making theory, where the fuzziness and grey of expert evaluation information can be used fully. As long as the marks are given to the influencing factors, the comprehensive evaluation value on the energy conservation of this residential building can be calculated, so as to achieve the reasonable and complete evaluation on each scheme. In addition, it is also noteworthy that the determination of the given marks and weights for a certain type of residential building has been rated by experts and approved by relevant departments. Upon approval and determination, they shall be treated equally, so as to reduce subjective factors during evaluation more and achieve higher objective fairness.

REFERENCES

[1] Li Lixin, Liu Lin, Wang Qiang; Comprehensive Evaluation Base on Grey Clustering Theory and Its Application in Safety Assessment of the Structure of the Construction Phase [J]. Shenyang: *Journal of Shenyang Jianzhu University*, **4**, 577-580 **(2008)**.

[2] Liu Shiming, Wei Jianmin, Bai Erhuang; Railway Safety Information Management System [M], Chengdu: *Southwest Jiaotong University Press*, **(1999)**.

[3] Guo Peng, Shi Pingui; Research on the Fuzzy Grey Comprehensive Evaluation Method for Project Energy Conservation [J], *Journal of Xi'an University of Technology*, **21(1)**, 106-109 **(2005)**.

[4] Liu Sifeng, Dang Yaoguo, Fang Zhigeng; An Introduction to Grey Systems, Methodology and Applications [M]. Beijing: *Science and Technology Press*, **(2007)**.