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Ningbo City's residential building energy efficiency evaluation index system

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Abstract. According to the actual situation in Ningbo, combined with both relevant information from both China's current building energy efficiency standards and that of foreign building's energy efficiency and environmental assessment methods, together established the Ningbo City residential building energy efficiency evaluation index system. Using the AHP application to evaluate, analyze and calculate to determine the weight of the evaluation index.

Introduction

In the construction industry, building energy conservation has been generally been considered as part of the country's policies. The purpose of the index systems is to aid in, as well as to help optimize the design. Building energy efficiency evaluation involves technical, economic, environmental and many other factors. Currently there are three internationally popular evaluation methods: rating method, life cycle assessment and the energy consumption calculation and simulation. Rating method users are: the national standard LEED (Leadership in Energy and Environmental Design) system established by the U.S. [1]; BREEAM (Building Research Establishment Environment Assessment Method) proposed by British; CASBEE (Comprehensive Assessment System for Building Environment Efficiency) developed by Japan [2]. Life cycle assessment methods users are: Hong Kong's LCEA (Life Cycle Energy Analysis) and the LCC (Life Cycle Cost). Energy consumption calculation and simulation methods users are: the British "standard evaluation procedures 2005" and Germany's "building energy passport".

On the aspect of architecture comprehensive performance evaluation and the green building evaluation, towards the end of 2003, by the Tsinghua University, China Academy of Building Research and other research institutions combined into a research team, published the first national evaluation of the green building, " Assessment System for Green Building of Beijing Olympic" [3]. "Green building evaluation criteria" (GB 50378-2006) [4] Beginning June 1, 2006 shall come into effect. Reflecting on the overall level of performance of national housing standard "Residential performance assessment technical standards" (GB50362-2005) [5] Beginning March 1, 2006 onwards. Currently, building energy efficiency evaluation studies are focused on the usage phase in the simulation. The methods used in the studies and indicators are relatively preliminary and partial. Mostly consider the buildings envelope thermal insulation performance, the air permeability of windows and doors, and equipment systems that operates independently of the effect. There is yet to be built a convincing and effective evaluation system for building energy-saving and weight distribution.

Ningbo City's residential building energy consumption factors

Residential building energy consumption is the energy that is consumed during the process when the resident uses energy. This mainly includes heating, air conditioning, hot water, cooking, lighting, and energy consumed by the elevator. For residential building energy efficiency, the first step is to know the factors affecting energy consumption. The main factors in Ningbo City's energy consumption in residential buildings are the following areas: (1) Overall planning. The overall planning and construction determines the direction and building density. If facing a different direction, the building would receive a different amount of solar radiation and natural ventilation therefore resulting in a big difference. (2) Building shape coefficient. The greater the shape factor, with the same volume in contact with the atmosphere outside the building, the greater the area. (3) Building envelope and window to wall ratio. Residential building envelope, including walls, doors and windows, roof, etc., is an important factor affecting energy consumption. Heat loss per unit area for the window compared to the wall is 4 times grater, so the window to wall ratio is an important factor of building energy consumption. (4) Heating and air conditioning systems. With general improvements in living standards, relying solely on the natural environment to adjust the interior environment simply can not be met. The need for heating and air conditioning systems is essential. Survey shows that in the recent three years in Ningbo, the overall increase in building energy consumption is based on air-conditioning and heating equipment, energy expenditure as the main energy expenditure.

Ningbo City's residential building energy efficiency evaluation index system

Construction method. First, using a comprehensive analysis of residential building energy efficiency evaluation index system of sources including: 1). sources on building energy efficiency evaluation index system, 2). foreign building energy efficiency and environmental assessment method, 3). China's current building energy-saving technology standards as well as 4). Ningbo City's building energy-efficiency related documents, a list of the residential evaluation was put together. Then, combing it with the Ningbo factors affecting energy consumption in residential buildings, according to scientific principles, the principle of systematic, a combined quantitative indicators and qualitative indicators formed principles and a multi-criteria decision-making rule, a list of indicators used for screening, thus an evaluation index system is formed - a rough draft. Finally, through the use of a questionnaire and consulting experts, amendment can be made to the evaluation. Ultimately, the establishment of Ningbo City's residential building energy efficiency indicators is completed (Fig. 1).

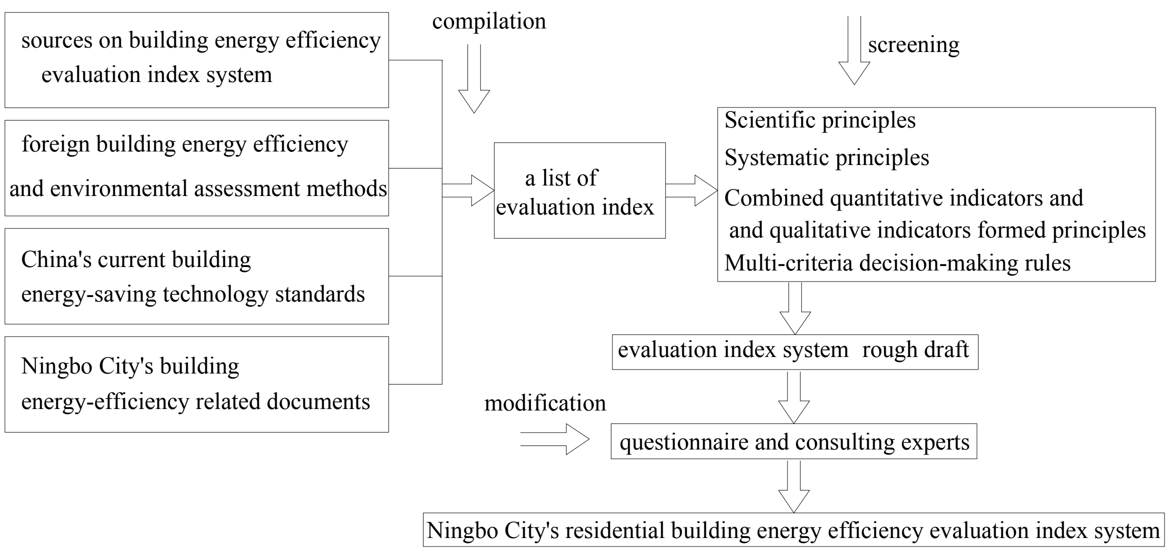

Figure 1. Residential building energy efficiency evaluation index system construction method

Principle of screening. (1) Scientific principles. Building energy assessment indicators selection and design must be based on the theory of sustainable development, environmental and ecological theory and statistical theory, based on such, the indicators have good stability. This paper, referenced foreign evaluation system such as LEED, BREAM's advanced concepts and from domestic standards, commonly used indicators. (2) Systematic principles. Constructed building energy efficiency evaluation index system is a complicated systematic project, reflecting the planning, structure, energy, equipment, materials, energy consumption that impact the buildings. This paper referenced evaluation tools SpeAR (r) (Sustainable Project Appraisal Routine), thus "economic viability" was included in an index, so that the whole system index would be more systematic and complete. (3) Quantitative indicators and qualitative indicators of the combination principle. To try to use quantitative indicators, for a problem that can not be quantitative, qualitative indicators can also be of help. (4) Multi-criteria decision-making rules. Building energy efficiency evaluation is a more complicated system, in essence, is a multi-criteria decision-making area.

Questionnaire and consulting. Experts pointed out that in recent years with the development of building energy efficiency, renewable energy sources use in construction applications is rapidly developing. In 2009, Ningbo City was recognized as the nation's first batch model city to use the renewable energy model application. This paper specifically puts "renewable energy "as an independent evaluation, included in the evaluation index system. Ningbo City's residential building energy efficiency evaluation index system show in Table 1.

Table 1. Ningbo City's residential building energy efficiency evaluation index system

Index No.	Primary Indicators	Serial No.	Secondary Indicators	Index No.	Primary Indicators	Serial No.	Secondary Indicators
1	Architectural design	A1	Building orientation	12	Construction equipment energy efficiency	C3	Energy efficiency of water supply and drainage system
2		A2	Building interval				
3		A3	Building shape coefficient	13		C4	Elevator equipment efficiency
4		A4	Outdoor environment	14	Construction operation and management	D1	Building energy management system
5		A5	Renewable energy	15		D2	Energy consumption statistics and publicity
6	Performance envelope	B1	Thermal insulation properties of Building envelope	16		D3	Operation and maintenance
7		B2	Air permeability	17		D4	Indoor environment
8		B3	Internal and external shading	18	Economic viability	E1	Construction capital
9		B4	Window to wall ratio	19		E2	Maintenance cost
10	Construction equipment energy efficiency	C1	Energy efficiency of HVAC system	20		E3	Equipment cost
11		C2	Lighting (energy) efficiency	21		E4	Investment recovery period

Evaluation to determine weight

AHP method. Analytical Hierarchy Process (AHP method) for determining the weight can decrease a person's subjective factors. This method has been developed earlier, and the development is more mature, but also convenient and easy. This paper uses AHP to determine the energy efficiency of residential buildings Ningbo City's index weights. Specific steps are as follows:

Step one: determine the building energy efficiency evaluation index system. Ningbo City's residential building energy efficiency evaluation system shown in Table 1. We take the primary indicators as an example.

Step 2: Using a questionnaire survey, to obtain specialist opinion of Ningbo City's residential building energy efficiency evaluation, in which to get the comparison matrix. Matrix elements are scaled from 1 to 9, detailed in Table 2 below:

Table 2. On a scale from 1 to 9, compares the importance of two factors

Scale	Meaning
1	Means two factors are compared, both have the same importance
3	Means two factors are compared, with the former slightly more important than the latter
5	Means two factors are compared, with the former obviously more important than the latter
7	Means two factors are compared, with the former greatly (strongly) more important than the latter
9	Means two factors are compared, with the former extremely more important than the latter
2，4，6，8	Means the adjacent median is the result
Reciprocal	If the factors x_i to factors x_j importance ratio is a_{ij}， then the factors x_j to factors x_i importance ratio is $a_{ji}= 1/ a_{ij}$

According to 10 Ningbo City residential building energy efficiency experts field survey, by integrating the results gathered from the experts,the following matrix below was obtained:

Primary Indicators	p_1 (A)	p_2 (B)	p_3 (C)	p_4 (D)	p_5 (E)
p_1 (A)	1	1/4	1/2	4	2
p_2 (B)	4	1	3	7	5
p_3 (C)	2	1/3	1	5	3
p_4 (D)	1/4	1/7	1/5	1	1/3
p_5 (E)	1/2	1/5	1/3	3	1

Step three: using the comparison judgment matrix to determine the index weights.Let the comparison matrix $A=(a_{ij})_{n\times n}$,which a_{ij} is $0<a_{ij}\le 9$; $a_{ii}=1$; $a_{ji}=1/a_{ij}$ .Index using the square root method calculate the weight W_i , as shown below：

（1）Calculate the comparison matrix $A=(a_{ij})_{n\times n}$ .The factor of each rows product： $X_i=\prod_{j=1}^{n} a_{ij}(i=1,2,\cdots n)$ ．

（2）Then n-th root the product get a vector $a_i=\sqrt[n]{X_i}(i=1,2,\cdots n)$,calculate the Primary Indicators matrix to get a vector $P=(1\quad 3.347\quad 1.585\quad 0.299\quad 0.631)$．

（3）Using the square root vector normalization processing,to get the index weight $W_i=a_i/\sum_{i=1}^{n}a_i$ with respect to comparison matrix $A=(a_{ij})_{n\times n}$,according to the above calculation,after normalization processing vector P ,to get weight vector $W=(0.146\quad 0.487\quad 0.231\quad 0.044\quad 0.092)$ ．

（4）Calculate maximum eigenvalue $\lambda_{\max}=\frac{1}{n}\sum_{i=1}^{n}\frac{(AW)_i}{W_i}=\frac{1}{n}\sum_{i=1}^{n}\frac{\sum_{j=1}^{n}a_{ij}W_j}{W_i}$, $\lambda_{\max}=5.137$.

（5）Do a consistency test：calculate the consistency index CI , $CI=\frac{\lambda_{\max}-n}{n-1}$,calculate the inconsistency ratio CR , $CR=\frac{CI}{RI}$,related RI (Random consistency ratio) can be found on table 3.When $CR\le 0.1$,if the comparison matrix consistency is acceptable,otherwise comparison matrix is need to be consistency regulated.From the above calculation get $CR=0.03\le 0.1$,the comparison matrix consistency is acceptable.

Table 3 Random consistency ratio Index

n	1	2	3	4	5	6	7	8	9	10	11	12	13
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49	1.52	1.54	1.56

The same AHP calculation method was applied to the secondary indicators and ultimately determined the reference item weights, as shown in Table 4:

Table 4 Ningbo City's residential building energy efficiency evaluation index weights

Primary Indicators	A					B				C	
Weight	0.146					0.487				0.231	
Secondary Indicators	A1	A2	A3	A4	A5	B1	B2	B3	B4	C1	C2
Weight	0.231	0.093	0.488	0.044	0.146	0.564	0.055	0.118	0.236	0.654	0.077
Primary Indicators	C		D				E				
Weight	0.231		0.044				0.092				
Secondary Indicators	C3	C4	D1	D2	D3	D4	E1	E2	E3	E4	
Weight	0.192	0.077	0.130	0.058	0.604	0.208	0.472	0.285	0.171	0.072	

Comprehensive energy saving evaluation

From the above analysis, the results identified Ningbo City's residential building energy efficiency evaluation system and its weight. From this bases, the system of indicators are to further be standardized, quantitative and determined for the criteria for each index score. For different buildings, one on one assessment criteria is done. For scoring, the final comprehensive energy evaluation can be obtained with ESEI (Energy Saving Effect Index), calculated as follows: $ESEI = \sum_{i=1}^{n} W_i S_i$,where, W_i is the weight of each index, S_i is each index score. The determination of the index score guidelines is a complex process. There is some subjectivity, because the actual construction location, function, etc. vary widely, both related to the development of guidelines to be simple and easy to operate, but also to achieve comprehensiveness and to be accurate, is very difficult. After obtaining the results from a final evaluation of the comprehensive energy-saving effect (ESEI). How to carefully divide the value range, for a score evaluation (such as excellent, good, pass and fail) conclusion, needs to be further explored for better results.

Conclusion

The architectural design decision of a building in its life cycle determines the energy saving level, and thus the effect on building energy saving efficiency. The effects of systematic assessment are to meet the energy requirements is essential. In this paper, the combined results of actual situation from Ningbo City, upon the basis of all comprehensive information and research from all sides, established Ningbo City's residential buildings energy conservation evaluation index system, and is confirmed by AHP method in determining the weight of each index.

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