557: A method of weighting indicators of energy efficiency assessment in residential building in China

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Abstract

This paper identifies the indicators of energy efficiency assessment in residential building in China through a wide literature review. Indicators are derived from three main sources: 1) The existing building assessment methods; 2)The existing Chinese standards and technology codes in building energy efficiency; 3)Academia research. As a result, we proposed an indicator list by refining the indicators in the above sources. Identified indicators are weighted by the group analytic hierarchy process (AHP) method. Group AHP method is implemented following key steps: Step 1: Experienced experts are selected to form a group; Step 2: A survey is implemented to collect the individual judgments on the importance of indicators in the group; Step 3: Members' judgments are synthesized to the group judgments; Step 4: Indicators are weighted by AHP on the group judgments; Step 5: Investigation of consistency estimation shows that the consistency of the judgment matrix is accepted. We believe that the weighted indicators in this paper will provide important references to building energy efficiency assessment.

Keywords: energy efficiency, residential building, assessment, weight

1. Introduction

The assessment of building energy efficiency is one of the most important issues in the building sector. The identification of indicators and the assignment of weights play key roles in building energy efficiency assessment. The role of weight serves to express the importance of each indicator relative to the others in a quantitative way. At fact, most of the existing rating building environment assessment methods contain weighted indicators (e.g. Leadership in Energy and Environmental Design LEED [1] and British Research Establishment Environmental Assessment Method BREEAM[2]). Moreover, cardinal weights of indicators are required while some mathematic model is employed to assess the building energy efficiency (e.g. evidential reasoning approach[3]) .

There are many methods which can be used to determine the weights of indicators. These methods can be classified into two main categories. One is an objective category, which calculates the weight by the past numerical value of each indicator. The essence of the category is the bigger the difference among the numerical value of the indicator is, the bigger the weight of the indicator. It is the same that the weight is small while the difference among the value of the indicator is small. An extreme example is if none of the buildings use any renewable energy, that means there is no diffidence among buildings on the renewable energy use. As a result, the weight of the indicator of 'The use of the renewable energy' should be 0. The methods of the category include the principal component analysis method, the factor analysis method, the grey incidence method, the entropy value method, the rank sum ratio method etc. The factor analysis method and the entropy value method are commonly used in the category[4, 5].The drawback of the objective category is that neither the decision maker's concern nor the experts' experiences about the energy efficiency assessment is taken into account. W. Edwards[6] stated that weights should reflect the purpose of the evaluation, the weights themselves indicate what the decision maker is most concerned about in decision or assessment. Therefore, we do not think the methods of the category are suitable to weight the indicators in the building energy efficiency.

The other category is a subjective category. The decision maker judges the relative importance of the indicator. The methods of subjective category include Delphi, Analytic Hierarchy Process (AHP), simple rank order, ratio weighting etc. Delphi and AHP are the two most commonly used in this category. The Delphi method was developed in RAND Corporation during the 1950-1960s (1959) by Olaf Helmer, Norman Dalkey, and Nicholas Resche. The Delphi method is a systematic interactive forecasting method for obtaining forecasts from a panel of independent experts. The carefully selected experts answer questionnaires in two or more rounds. Participants are encouraged to revise their earlier answers in light of the replies of other members of the group. The process is stopped after a pre-

defined stop criterion (e.g. number of rounds, achievement of consensus, stability of results) [7]. However, the drawback of the Delphi method is very time consuming and the cost is high.
Group AHP is used to weight the indicators in the energy efficiency assessment in building rather than the Delphi method. The reason is Group AHP enjoys the advangate of the Delphi method on a group decision,whereas it addresses the weakness of Delphi on time consuming and high cost. Both methods are based on the jugdement of a group which includes the experienced experts. Compared with individual decision making, group decision enjoys many merits such as avoiding extreme preference. Group AHP method needs only one round conmunication with experts, as a result, the group AHP method takes lesser time and cost than the Delphi method.
In the current paper, we illustrate the use of the group AHP to weigh the indicators in building energy efficiency assessment. It is organized as follows. In section 2, we demonstrate the identification of indicators in building energy efficiency assessment. In section 3, we illustrate the implement of the Group AHP in weighting indicators. The summary and conclusions are made in section 4.

2. Indicators derivation

There are many indicators sources for energy efficiency assessment in residential building. The indicators in this paper are mainly derived from the three main sources.1) Existing building assessment methods. At present, the international popular building assessment methods include LEED, BREEAM, Comprehensive Assessment System for Building Environmental Efficiency (CASBEE)[9], GBTOOL etc. Energy efficiency assessment is one important part of them, so these methods provide inspiration to the identification of the indicators for building energy efficiency assessment. 2) Existing Chinese standards and technology codes in building energy efficiency. Building assessment should be combined with the current domestic standards and codes, otherwise, the assessment method will encounter practical difficulties.China is divided into five climate zones: serious cold zone, cold zone,hot summer cold winter zone, hot summer warm winter zone,and mild zone.At present, there are design standards for energy conservation of residential building in four climate zones except mild zone. ‘Energy conservation design standard for heating in new residential buildings’ JG9 26—95[10] is for the serious cold zone and cold zone. ‘Design standard for energy efficiency of residential building in hot summer and cold winter zone’ JGJ 134-2001[11]， ’Design standard for energy efficiency of residential buildings in hot summer warm winter zone’ JGJ 75-2003[12]. Meanwhile, ‘Code of thermal design for residential buildings’ GB 50176-93[13] and ‘Code for design of heating ventilation and air conditioning’(GB 50019-2003) described in detail thermal design for envelope and HV&AV system[14]. In addition, ‘technical standard for performance assessment of residential building’ (GB/T 50362—2005)[15] assesses the comprehensive performance of residential buildings from the five aspects, effectiveness, environmental impacts, economy, security and permanent. ‘Evaluation standard for green building’（GB 50378-2006)[16] covers the six factors: land conservation and outdoor environment, energy conservation and use, Water conservation and use, material conservation and use, Indoor environment quality and operation and management. 3) Academia research. Academic research highlights the innovation of the energy efficiency assessment. We considered some academic research results in the discipline while the identification of indicators. For example, at the end of year of 2003,’Green Olympic building assessment system’[17] was proposed, it is the first green building assessment system in China.
The indicators in above sources are refined by the following rules: 1) Feasibility to attain the value of the indicator. For example, the all year real heating energy consumption could be an essential indicator. However, it costs too much time and money to get its value and there is still technical difficulty to get it at present. Therefore, we do not regard the all year real heating energy consumption as an indicator. 2) Reasonable number of indicators. Yoon [18] stated that seven plus or minus two represents the greatest amount of information that an observer can give us about an object on the basis of an absolute judgment. 3) Mutually exclusive indicators. This would help prevent undesirable "double-counting" in weighting the indicators. The final selected indicators are listed in Table 1.

Table 1:Indicators of energy efficiency assessment in residential building

Order	Categories	Indicators
1	CT1.Space heating and cooling load	A1.Heat insulation of envelope
2		A2. Air tightness of envelope
3		A3.Orientation of building
4		A4.Outdoor and indoor shadow
5		A5.Nature ventilation
6	CT2.Efficiency of building facilities	B1.Efficiency of boiler/chiller units
7		B2.Efficiency of air treatment units
8		B3. Indoor air distribution
9		B4.Efficiency of water pumps
10		B5.Efficiency of lifts
11		B6.Efficiency of lighting facilities
12	CT3.Use and reuse of construction material	C1.Use of low embodied energy material
13		C2.Reuse of material
14		C3.Advanced design and construction technique
15		C4. Use of local material
16	CT4.Operation and management	D1.Adjustment of building facilities
17		D2.Heat/cool consumption measure by occupant in

		central heating/cooling system
18		D3.Energy cost for operation of building
19		D4. Investment and reclaim periods of building energy efficiency
20		D5.Training and spread of building energy conservation knowledge
21	CT5.Use of renewable energy	E1.Proportion of renewable energy in building energy consumption
22		E2.Use of local renewable energy sources
23		E3.Cost of the renewable energy
24	CT6.Indoor comfort and healthy	F1.Indoor thermal comfort
25		F2. Indoor lighting

3. Apply group AHP to weight indicators

3.1 Group AHP method

AHP method was developed by Saaty[19] in the 1970's, is an approach to multi-criteria decision making problems of choice and prioritization. In 1983, Aczel and Saaty[20] proved that the geometric mean is the unique appropriate rule to combine individual judgments to group judgments in AHP, since it preserves the reciprocal property of the judgment matrix. In 2005, Saaty and Vargas[21] demonstrated two ways for AHP to construct a welfare function for a group from individual function. Saaty and Shang[22] presented an application of AHP in a group decision system(voting system) in 2007. AHP is a widely used decision analysis methodology around the world today. There are many applications of AHP in building assessment or decision-making[23,24,25,26,27]. Nevertheless, to the best of our knowledge, we have not found a literature review for AHP is used in building energy efficiency assessment under a group decision situation so far.

In a group decision, it is proposed that there generally is a continuum of decision making contexts ranging from (1) common objectives – all member have the same objectively;(2) non-common objectives – members have non-shared objectives;(3)conflict–members seek concessions from opposing parties. Dyer and Fornest[28] stated that because the AHP model is structured and flexible, it is a powerful and straightforward methodology that can be integrated into almost any group decision support system.

There are at least two ways for a group to weight the indicators in building energy efficiency assessment. One is group members meeting to consensus; the other is forming members' individual's judgments for group judgments by mathematic method. For the first way, members meet as a group and strive for consensus. This approach is attractive, nevertheless, it costs more money and time, it gets worse while experts are far away from each other and busy. If a consensus cannot be obtained from the first way, the second way is a considerable alternative. In this paper, we take the group AHP method to weight the indicators in building energy efficiency assessment rather than group members meeting to consensus.

3.2 Organize group and harvest individual judgements

A group consisting of ten experienced professionals is organized to assess the relative importance of the indicators in building energy efficiency assessment. Table 2 shows some professional background of the group members.

Table 2: Professional background of group members

Ord	Discipline	YCD	Title	Education
Me1	Professional journal editor	11-15	Editor	Bachelor
Me2	Construction industry	11-15	Senior engineer	Master
Me3	Management and operation of building	11-15	Engineer	Bachelor
Me4	Building design and research	16-20	Senior engineer	Bachelor
Me5	Construction industry	6-10	Engineer	Bachelor
Me6	Building design and research	Over 20	Senior engineer	Bachelor
Me7	Building services design and research	3-5	Engineer	Bachelor
Me8	Building services design and research	6-10	Engineer	Bachelor
Me9	Building services design and research	6-10	Engineer	Bachelor
Me10	Building services design and research	6-10	Engineer	Bachelor

Me=Group member, YCD=Years on current discipline

In AHP the assessor judges the importance of indicators through paired comparison. Judgments are represented by a comparison matrix. Suppose there are n indicators to be weighted, the comparison matrix should be n rows and n column, a_{ij} is element in row i,column j, a_{ij} represents the judgment of relative importance between indicator i and indicator j, and $a_{ji} = 1/ a_{ij}$. The numerical values of the comparison matrix element is determined by member's pairwise comparison under Saaty's nine-points scale, the details of nine-points scale are listed in table 3.

Table 3: nine-point scale for the relative importance judgments

a_{ij}	Definition
1	Indicator i and indicator j are equal importance
3	Indicator i is weak important than indicator j
5	Indicator i is strong important than indicator j
7	Indicator i is demonstrably important than indicator j
9	Indicator i is absolutely more important than indicator j
2, 4, 6,	Intermediate values between the above two adjacent judgments

8	
a_{ji}	$a_{ji} = 1/a_{ij}$

A questionnaire consisting of 11 question sheets is designed and sent to each member in the group. Table 4 is an example question in a question sheet. One question sheet is for the relative importance of categories. As table 1 shows, each category consists of several indicators, 5 question sheets for 5 categories to assess their indicators except the category of 'CT1:Space heating and cooling load'. Since climate has significant impacts on the category of 'Space heating and cooling load', 5 question sheets are designed to assess the indicators by five climate zones in China on this category. Therefore, there are 11 question sheets in total, and each answered question sheet yields relevant comparison matrixes.

Table 4. An example in Questionnaire

Question:In order to assess the building energy efficiency, which is more important between the following two indicator A and indicator B?（Please mark your selection with '√'）
A)'Reduction of the heating and cooling load' B)'Improvement of the efficiency of building facilities' A_____ B____.Its importance can be described with the following statement:
1) 'equal importance'____； 2) Intermediate between 'equal importance' and 'weak important' ____； 3) 'weak important'____ ； 4) Intermediate between 'weak important' and 'strong important'____； 5) 'strong important'____ ； 6) Intermediate between 'strong important' and 'demonstrably important'____； 7) 'demonstrably important'____ ； 8)Intermediate between 'demonstrably important' and 'absolutely important'____ ； 9) 'absolutely important'____；

3.3 synthesize individual judgments to group judgments

As we have described before, it has been proved that the geometric mean is the unique appropriate rule to combine individual members' judgments to group judgments in group AHP. Group comparison matrixes are attained from the geometric mean of the elements of individual members' comparison matrixes. Based on the aggregated group comparison matrixes, the weights are calculated by the primary eigenvalue of the group comparison matrixes. The consistency ratio (C.R.) represents the consistency judgments in AHP. The less the C.R. is, the better the consistency is. Saaty stated that a C.R. less than 0.1 is accepted[19].

So, the Weights of categories and the C.R. of category group comparison matrix are listed in Table 5. Local weights of indicators and the C.R. of each group comparison matrix on each category are listed in Table 6. Table 5 and Table 6 show that C.R. is far less than 0.10 in each group comparison matrix. As a result,It is safe to say the consistency in our survey is satisfactory.

Table 5. Weights of categories and the consistency ratio of category group comparison matrix

Category	Weight
CT1. 'Space heating and cooling load'	0.23
CT2. 'Efficiency of building facilities'	0.14
CT3. 'Use and reuse of construction material'	0.12
CT4. 'Operation and management'	0.17
CT5.'Use of renewable energy'	0.15
CT6.'Indoor comfort and healthy'	0.19
Sum	1.00
C.R.	0.05

Table 6. Local weights of indicators and the consistency ratio of each group comparison matrix on each category

Category	**Indicator**	**Local weight**	**C.R.**
CT1.'Space heating and cooling load'(Serious cold zone)	A1	0.36	0.01
	A2	0.16	
	A3	0.25	
	A4	0.09	
	A5	0.14	
	sum	1.00	
CT1.'Space heating and cooling load'(Cold zone)	A1	0.36	0.01
	A2	0.18	
	A3	0.21	
	A4	0.09	
	A5	0.10	
	sum	1.00	
CT1. 'Space heating and cooling load'(Hot summer cold winter zone)	A1	0.31	0.00
	A2	0.11	
	A3	0.23	
	A4	0.12	
	A5	0.23	
	sum	1.00	
CT1. 'Space heating and cooling load'(Hot summer warm winter zone)	A1	0.26	0.01
	A2	0.11	
	A3	0.18	
	A4	0.20	
	A5	0.25	
	sum	1.00	
CT1. 'Space heating and cooling load'(Mild zone)	A1	0.23	0.01
	A2	0.13	
	A3	0.28	
	A4	0.13	
	A5	0.23	
	sum	1.00	
CT2. 'Efficiency of building facilities'	B1	0.30	0.02
	B2	0.20	
	B3	0.16	
	B4	0.15	
	B5	0.07	
	B6	0.11	
	sum	1.00	
CT3. 'Use and reuse of construction material'	C1	0.39	0.02
	C2	0.24	
	C3	0.26	
	C4	0.11	
	sum	1.00	
CT4. 'Operation and management'	D1	0.24	0.04
	D2	0.13	
	D3	0.29	
	D4	0.22	
	D5	0.12	
	sum	1.00	
CT5.'Use of renewable energy'	E1	0.23	0.01
	E2	0.40	
	E3	0.37	

	sum	1.00	
CT6.'Indoor comfort and healthy'	F1	0.61	0.00
	F2	0.39	
	sum	1.00	

3.4 Weighting the indicators

Overall weights of indicators are yielded by the indicators' local weights multiplied with its category's weights in Table 5. The overall weights of indicators are listed in Table 7.

Table 7. Weights of indicators in energy efficiency assessment in residential building in China

Indicator	**Serious cold zone**	**Cold zone**	**Hot summer cold winter zone**	**Hot summer warm winter zone**	**Mild zone**
A1	0.09	0.09	0.08	0.06	0.06
A2	0.04	0.04	0.03	0.03	0.03
A3	0.06	0.05	0.06	0.05	0.07
A4	0.02	0.02	0.03	0.05	0.03
A5	0.03	0.04	0.06	0.06	0.06
B1	0.04	0.04	0.04	0.04	0.04
B2	0.03	0.03	0.03	0.03	0.03
B3	0.02	0.02	0.02	0.02	0.02
B4	0.02	0.02	0.02	0.02	0.02
B5	0.01	0.01	0.01	0.01	0.01
B6	0.01	0.01	0.01	0.01	0.01
C1	0.04	0.04	0.04	0.04	0.04
C2	0.03	0.03	0.03	0.03	0.03
C3	0.03	0.03	0.03	0.03	0.03
C4	0.01	0.01	0.01	0.01	0.01
D1	0.04	0.04	0.04	0.04	0.04
D2	0.02	0.02	0.02	0.02	0.02
D3	0.05	0.05	0.05	0.05	0.05
D4	0.04	0.04	0.04	0.04	0.04
D5	0.02	0.02	0.02	0.02	0.02
E1	0.04	0.04	0.04	0.04	0.04
E2	0.06	0.06	0.06	0.06	0.06
E3	0.06	0.06	0.06	0.06	0.06
F1	0.11	0.11	0.11	0.11	0.11
F2	0.07	0.07	0.07	0.07	0.07
Sum	1.00	1.00	1.00	1.00	1.00

From table 5 and table 7, a brief summary of the findings is represented as follows.

- 'CT1.Space heating and cooling load' is perceived as the most important core category for the energy efficiency assessment in residential building in China. The dominance rank of remaining categories is 'CT6.Indoor comfort and healthy contribute' > 'CT4.Operation and management'>'CT5.Use of renewable energy'>'CT2.Efficiency of building facilities'>'CT3.Use and reuse of construction material'. However, weights of categories show that there is a balance among the categories, in other words, neither category absolutely overwhelms others, nor category can be ignored due to extreme low weight.
- 'A1.Heat insulation of envelope' plays the overwhelming role in the assessment of category of 'CT1.Space heating and cooling load' in serious cold zone, Cold zone and Hot summer cold winter zone. However, in mild zoned, 'A3.Orientation of building', 'A4.Outdoor and indoor shadow' and 'A5.Nature ventilation' are the most three important indicators. There is a balance in indicators in hot summer warm winter zone.

4. Conclusion

This paper identifies the indicators of energy efficiency assessment in residential building in China through a wide literature review. Group AHP method is used to weight the identified indicators. It is our expectation that the weighted indicators in this paper will provide references to building energy efficiency assessment. In addition, we believe that the group AHP method used in this paper has potential application in other aspects in building assessment.

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