

The Establishment for The Buildings Energy-efficiency Large System in Sanjiangyuan Area with Analytic Hierarchy Process

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Abstract: It is found that a theoretical system for energy-efficient solutions of buildings in Sanjiangyuan area is difficult to establish due to the complexity in quantitative analysis on some factors. Therefore, based on a preliminary analysis on the complex nature of the decision making process of building energy efficiency in three-river source area, and influential factors on the issue, it is recognized that Analytic Hierarchy Process (AHP) is an efficient approach for analyzing and discussing the establishment of the system, and thus a guideline can be set up for some pilot projects.

Define a Hierarchical Structure

Our research team wants to optimize the overall benefits of the solution to building energy efficiency in three-river source area by analyzing different alternatives. The goal of our study is to make efficient use of clean energy and optimize the overall benefits.

In order to achieve the goal, the three main criteria for assessing the outcome should be considered are economic benefit, social benefit and environmental benefit, among which environmental benefit is the most important criterion. After further discussion, we think that the three main criteria should be classified under some more detailed criteria including direct economic benefit, indirect economic benefit, energy resources, energy with advantage, minimization of pollution, improvement of urban landscape, recognition of residents in the area.

It is assumed that only the criteria mentioned above are analyzed, and with these criteria some specific alternatives for improving building energy efficiency can be proposed. The research provides two alternatives, including clean energy (solar energy and wind energy) and insulation structure. It is evident that these two alternatives are relevant to all the criteria mentioned, so they are factors at alternative level, the lowest level of the hierarchical structure.

The factors are put at different levels following the interrelationships between them, and linked by lines. In order to assist quantitative analysis, from the top to the bottom the levels are marked with A, B, C, D, etc. And from left to right different factors are marked with 1, 2, 3, 4, etc (Fig.1).

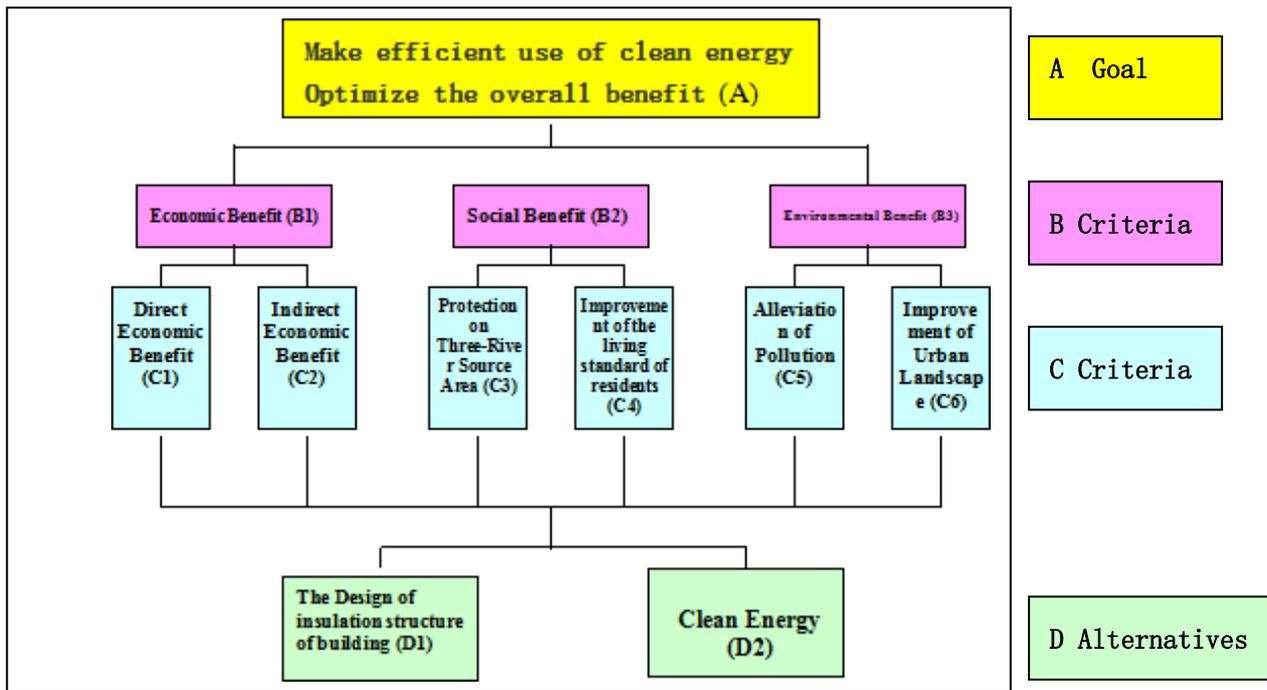


Fig. 1 Hierarchical Structure

Comparison Matrix and Evaluation of Experts

Comparison Matrixes can be made based on the hierarchical structure. The method of making a comparison matrix is to put each factor with subordinate factors (criteria) in the top left corner as the first factor in a matrix, and its subordinate factors are put in the first line and the first column following their numbers^[1]. The method for evaluating the criteria is to consult 13 experts by correspondence. They are asked to determine the level of importance of these factors by compare them in pairs, and the level of importance scored from 1 to 9 (table 2-1).

Table 2-1 Scales of importance

Scales of importance	Description
1	The compared two factors are equally important
3	One factor is a little more important than the other
5	One factor is obviously more important than the other
7	One factor is much more important than the other
9	One factor is extremely more important than the other
2, 4, 6, 8	Between the scales above
reciprocal	If the ratio between factor i and factor j is a_{ij} , ratio between factor j and factor i is a_{ji} , equaled to $1/a_{ij}$.

After consulting experts, comparison matrixes can be made (table 2-2).

Table 2-2 comparison matrixes

A	B1	B2	B3	B1	C1	C2	B2	C3	C4	B3	C5	C6
B1	1	1/3	1/7	C1	1	1/3	C3	1	7	C5	1	5
B2		1	1/5	C2		1	C4		1	C6		1
B3			1									

C1	D1	D2	C2	D1	D2	C3	D1	D2	C4	D1	D2
D1	1	5	D1	1	1/3	D1	1	1/8	D1	1	5
D2		1	D2		1	D2		1	D2		1

C5	D1	D2	C6	D1	D2
D1	1	1/7	D1	1	1/5
D2		1	D2		1

Single Hierarchical Arrangement and Test (Calculation of weight vector)

According to the results of comparison matrixes from the experts, Rankings can be made with some mathematic methods. Single hierarchical arrangement is to calculate the relative weight of each factor compared with its criteria, so its nature is to calculate weight vector. In this research sum method is used to calculate weight vector. Sum method means that in a consistent comparison matrix, the result of normalization is weight vector, while in an inconsistent comparison matrix, the result of normalization is almost equaled to its vector, and the weight is the arithmetic average value of the vector of the total n columns. The equation is as Eq. 1.

$$W_i = \frac{1}{n} \sum_{j=1}^n \frac{a_{ij}}{\sum_{k=1}^n a_{kj}} \quad (1)$$

After the rankings for each level, the comparison matrixes should be tested with their level of consistency. A matrix is logically justified only if it passes the test, after which the result of a matrix can be analyzed.

The procedures of the test for evaluating the consistency are as following^[2]:

Step 1 Calculate the consistency index(C.I.)of each matrix.Eq. 2.

$$C.I. = \frac{\lambda_{\max} - n}{n - 1} \quad (2)$$

Step 2 Find out the random index (R.I.) of each matrix by looking up table 3-1.

Table 3-1 Random Index

Order of Matrix	1	2	3	4	5	6	7	8
R. I.	0	0	0.58	0.90	1.12	0.24	1.32	1.41
Order of Matrix	9	10	11	12	13	14	15	
R. I.	1.45	1.49	1.52	1.54	1.56	1.58	1.59	

Step 3 Calculate consistency ratio (C.R.), based on which, make judgement. Eq. 3.

$$C.R. = \frac{C.I.}{R.I.} \quad (3)$$

If $C.R. < 0.1$, its level of consistency is acceptable, while if $C.R. > 0.1$, its level of consistency is unacceptable, and revision should be made in the matrix. According to the formula (3), the weight vector and test results obtained from this study shown in Table 3-2.

Table 3-2 weight vector and results of test

A	Single (Overall) Ranking Weight	B1	Single Ranking Weight	B2	Single Ranking Weight	B3	Single Ranking Weight
B1	0.1412	C1	0.4500	C3	0.7500	C5	0.6500
B2	0.4187	C2	0.5500	C4	0.2500	C6	0.3500
B3	0.4401	CR	0.0000	CR	0.0000	CR	0.0000
CR	0.0000						
C1	Single Ranking Weight	C2	Single Ranking Weight	C3	Single Ranking Weight	C4	Single Ranking Weight
D1	0.8212	D1	0.7500	D1	0.1782	D1	0.7991
D2	0.1788	D2	0.2500	D2	0.8218	D2	0.2009
CR	0.0000	CR	0.0000	CR	0.0000	CR	0.0000
C5	Single Ranking Weight	C6	Single Ranking Weight				
D1	0.1682	D1	0.2300				
D2	0.8318	D2	0.7700				
CR	0.0000	CR	0.0000				

The results show that all the consistency ratios under single hierarchy arrangement are less than 0.1, which means that the level of consistency of each comparison matrix is acceptable.

Overall ranking and test

Overall ranking aims at working out the weight of each factor versus the factors at Level A (Goal). The calculation starts from the top to the bottom. The equation to calculate the weight of factors of level k versus the goal is as Eq.4

$$w_i^{(k)} = \sum_{j=1}^m p_{ij}^{(k)} w_j^{(k-1)} \quad i=1,2,\dots,n \quad (4)$$

The overall ranking result also should be tested for the level of consistency. The equation is as Eq.5.

$$CR^{(k)} = \frac{CI^{(k)}}{RI^{(k)}} \quad (5)$$

If $CR^{(k)} < 0.1$, The level of consistency of the comparison matrix is acceptable.

After considering the influence factor δ of the number of experts, the overall ranking result and consistency test result of this research can be found in table 3-3 and table 3-4.

Table 3-3 Overall Ranking of Level C (CR=0.0000)

C1	C2	C3	C4	C5	C6
0.0412	0.0463	0.3525	0.1081	0.3511	0.1008

Table 3-4 Overall Ranking of Level D (CR=0.0000)

D1	D2
0.3512	0.6488

It is evident that the $CR < 0.1$. Therefore, the overall consistency of these comparison matrixes is acceptable.

Conclusion

The solution can be found by analyzing the results of rankings.

According to the results of rankings of level D (Alternatives), the weight of clean energy (D2)(0.6488) is much higher than the weight of the design of insulation structure of buildings (D1)(0.3512). Therefore, according to the common view of the experts, the use of clean energy should be the final solution for improving building energy efficiency in three-river source area.

Decision making analysis

Comparing the three factors in level B (Criteria), the weight of economic benefit (B1) is the lowest (0.1412), following social benefit (B2) and environmental benefit (B3)(0.4187 and 0.4401). It means that social benefit and environmental benefit, especially the latter one, are more emphasized.

Comparing the factors under economic benefit, for both direct economic benefit (C1) and indirect economic benefit (C2), the weight of clean energy is much higher than that of the design of insulation structure under single hierarchical arrangement. In addition, for three of the four factors under social benefit and environmental benefit, the weight of the clean energy is also much higher than that of the design of insulation structure under single hierarchical arrangement. Therefore, due

to more contribution to social benefit and environmental benefit, clean energy is with more significant weight.

According to the ranking result of Level C (Criteria), protection on three-river source area (C3 is 0.3525) and alleviation of pollution (C5 is 0.3511) are almost same, and for each of the criterion, the weight of clean energy is much higher than that of insulation structure.

In conclusion, according to the analysis above, social benefit and environmental benefit, rather than economic benefit, are more emphasized in this decision making process. Furthermore, two factors including protection on Sanjiangyuan area and alleviation of pollution are put higher priority, and for both of them, clean energy is the better alternative. Therefore, it is justified that the utilization of clean energy is an efficient approach for energy-efficient solution for buildings in Sanjiangyuan area.

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