A study on energy-efficient building scheme selection by heterogeneous VIKOR

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Abstract: Energy efficiency is emphasized as a main indicator for construction techniques for different types of buildings. This paper carries out an energy-efficient study on energy-efficient scheme selection by utilization of VIKOR (Vlsekriterijumska optimizacija i KOmpromisno resenje). Firstly, the member of construction shall be designed to present various schemes as alternatives. Secondly, experts are invited to give evaluation on attributes of alternatives. Besides, relevant indicators can be derived from on-site experiment or simulation. Thirdly, energy-saving schemes are ranked by the heterogeneous multi-attribute decision technology of VIKOR. The application would provide practical guidance optimal selection for construction techniques of certain energy-efficient members.

1. Introduction

It widely acknowledged that building sector account for a large percentage of total energy consumption in recent decades [1, 2], especially when construction process is considered [3]. Therefore, it is highly essential to figure out the most energy efficient construction technique to construct certain members of buildings, for example, the optimal technique for roof, walls, etc. [4, 5]

There are indeed a large variety of decision-making methods to be applied such as TOPSIS, AHP, ANP, etc. [6] However, application of these methods in construction techniques is quite rare. In this study, the author proposes a method to evaluate techniques based on VIKOR with heterogeneous attributes. Hopefully, it can provide hints to optimal selection in construction of building members. In the following part, the method is introduced.

2. VIKOR with heterogeneous attributes

VIKOR method is a compromised ranking method proposed by Opricovic based on the positive and negative ideal points [7]. This method is introduced as an effective technique to rank alternatives with respect to conflicting criteria based on an aggregating function that can measure the distance to ideal solutions [2]. The fundamental principles of VIKOR method are based on L_p-metric aggregating function represented as follows.

$$L_{pi} = \left\{ \sum_{j=1}^{n} W_j \left[\left(\frac{f_j^* - f_{ij}}{f_j^* - f_j^-} \right) \right] \right\}^{\frac{1}{p}}, 1 \le p \le +\infty; i = 1,2,...,I \tag{1}$$

where f_j^* and f_j^- are the positive and negative ideal points. Suppose that there are m multi-attribute decision alternatives and n attributes, which could be denoted as $K = \left\{ K_1, K_2, ..., K_m \right\}^T, A = \left\{ A_1, A_2, ..., A_n \right\}^T$ respectively. The evaluation value of j^{th} criterion for alternative K_i can be denoted as $k_{ij} (1 \le i \le m, 1 \le j \le n)$.

The specific steps of VIKOR method are as follows.

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Step 1. Establish the normalized decision matrix. Matrix $K=(k_{ij})_{m\times n}$ can be normalized into decision matrix $L=\left(l_{ij}\right)_{m\times n}$. For the sake of this study, indicators including crisp number, triangle fuzzy number would be normalized in the heterogeneous multi-attribute decision-making problem.

(1) Normalization of crisp number.

$$
\begin{aligned}
& l_{ij}=k_{ij}\,/\,\sqrt{\sum_{i=1}^{m}k_{ij}^{2}},\left(1\le i\le m,1\le j\le n\right),\ \textbf{for benefit attribute}\\
& l_{ij}=\frac{1}{k_{ij}}\,/\,\sqrt{\sum_{i=1}^{m}\frac{1}{k_{ij}^{2}}},\left(1\le i\le m,1\le j\le n\right),\ \textbf{for cost attribute}
\end{aligned}
\tag{2}
$$

(2) Normalization of triangle fuzzy number

The original TFN $(a_{ij}^{\,l},a_{ij}^{\,m},a_{ij}^{\,r})$ can be normalized into $(b_{ij}^{\,l},b_{ij}^{\,m},b_{ij}^{\,r})$ through the following method:

$$
\begin{cases}
b_{ij}^{\,l}=a_{ij}^{\,l}\,/\,\sqrt{\sum_{i=1}^{n}\left(a_{ij}^{r}\right)^{2}}\\
b_{ij}^{\,m}=a_{ij}^{\,m}\,/\,\sqrt{\sum_{i=1}^{n}\left(a_{ij}^{m}\right)^{2}},\left(1\le i\le m,1\le j\le n\right),\ \textbf{for benefit attribute}\\
b_{ij}^{\,r}=a_{ij}^{\,r}\,/\,\sqrt{\sum_{i=1}^{n}\left(a_{ij}^{l}\right)^{2}}
\end{cases}
\tag{3}
$$

$$
\begin{cases}
b_{ij}^{\,r}=\left(\frac{1}{a_{ij}^{\,r}}\right)/\sqrt{\sum_{i=1}^{n}\left(\frac{1}{a_{ij}^{l}}\right)^{2}}\\
b_{ij}^{\,m}=\left(\frac{1}{a_{ij}^{\,m}}\right)/\sqrt{\sum_{i=1}^{n}\left(\frac{1}{a_{ij}^{m}}\right)^{2}},\left(1\le i\le m,1\le j\le n\right),\ \textbf{for cost attribute}\\
b_{ij}^{\,l}=\left(\frac{1}{a_{ij}^{l}}\right)/\sqrt{\sum_{i=1}^{n}\left(\frac{1}{a_{ij}^{r}}\right)^{2}}
\end{cases}
\tag{4}
$$

(3)Linguistic indicator can be transformed into triangle fuzzy number presented in the Table 1 by the normalization method mentioned above, and can be normalized. In our evaluation index system, on-site Quality controllability (C_{21}), level of technical convenience (C_{22}), waterproof ability (C_{31}), fireproof ability (C_{32}), quality stability of service life (C_{41}) can be expressed in TFN according to Table 1.

Table 1 Transformation of linguistic variables into triangle fuzzy number

Linguistic variables	TFN
Good	(0.75,1,1)
Relatively good	(0.5,0.75,1)
Medium	(0.25,0.5,0.75)
Relatively weak	(0,0.25,0.5)
Weak	(0, 0,0.25)

Step 2. Determine Positive Ideal solution (PIS) and Negative Ideal Solution (NIS). Suppose weight vector is $w=\left\{w_1,w_2,...,w_n\right\}^T$. Based on the normalized matrix, PIS vector is denoted as $G^{+}=\left\{g_1^{+},g_2^{+},...,g_n^{+}\right\}$, and NIS vector is denoted as $G^{-}=\left\{g_1^{-},g_2^{-},...,g_n^{-}\right\}$

PIS and NIS can be obtained by the following equations respectively:

$$G^{+}=\begin{cases}\min\limits_{i} G_{ij}, j \text{ belongs to cost attribute} \\ \max\limits_{i} G_{ij}, j \text{ belongs to benefit attribute}\end{cases}, j=1,2,...,n. \tag{5}$$

$$G^{-}=\begin{cases}\min\limits_{i} G_{ij}, j \text{ belongs to cost attribute} \\ \max\limits_{i} G_{ij}, j \text{ belongs to benefit attribute}\end{cases}, j=1,2,...,n. \tag{6}$$

The distance from i^{th} alternative to PIS: $d_i^{+}=\sqrt{\sum_{j=1}^{n}\left(g_{ij}-g_j^{+}\right)^2}, i=1,2,...,m.$

The distance from i^{th} alternative to NIS: $d_i^{-}=\sqrt{\sum_{j=1}^{n}\left(g_{ij}-g_j^{-}\right)^2}, i=1,2,...,m.$

Step 3. Calculate S_i, R_i *and* Q_i

$$\begin{aligned} S_i &= \sum_{j=1}^{n}\frac{w_j D\left(g_j^{+}, l_{ij}\right)}{D\left(g_j^{+}, g_j^{-}\right)} \\ R_i &= \max_j\left[\frac{w_j D\left(g_j^{+}, l_{ij}\right)}{D\left(g_j^{+}, g_j^{-}\right)}\right] \\ Q_i &= v\frac{\left(S_i-S^{-}\right)}{\left(S^{+}-S^{-}\right)}+\left(1-v\right)\frac{\left(R_i-R^{-}\right)}{\left(R^{+}-R^{-}\right)} \end{aligned} \tag{7}$$

Where $S^{+}=\max\limits_j S_i, S^{-}=\min\limits_j S_i, R^{+}=\max\limits_j R_i, R^{-}=\min\limits_j R_i$, v represents coefficient of maximization of group utility. This paper takes v= 0.5, which means the alternatives are evaluated in a balanced and compromised way.

Step 4. Determine the rank of S_i, R_i *and* Q_i. Rank the value of S_i, R_i *and* Q_i in an increasing order. Thus, the previously ranked alternative is better than the latter one. The new order is expressed as $A_{(1)},...,A_{(i)},...,A_{(m)}$.

Step 5. Find out the compromised alternative. If $A_{(1)}$ satisfies the conditions 1 and 2, $A_{(1)}$ is considered as the optimal alternative with the minimum Q_i. Condition 1: $Q\left(A_{(1)}\right)$is chosen if $Q\left(A_{(2)}\right)-Q\left(A_{(1)}\right)\geq 1/_{n-1}$; Condition 2: $Q\left(A_{(1)}\right)$ also obtains first rank according to values of S_i and/or R_i.

3. Case study

In our research, there are four multi-attribute decision alternatives and eight sub-criteria, which could be denoted as $K=\left\{K_1,K_2,K_3,K_4\right\}^T, A=\left\{A_1,A_2,...,A_8\right\}^T$ respectively. The evaluation value of j^{th} criterion for alternative K_i can be denoted as $k_{ij}(i=1,2,3,4; j=1,2,...,8)$. The specific steps of VIKOR method are as follows: for the sake of this study, indicators including crisp number, triangle fuzzy numbers are normalized. The normalized evaluation result is illustrated in Table 2. Then we determine Positive Ideal solution (PIS) and Negative Ideal Solution (NIS) as follows:

$$G^{+}=\left[0.65\ (0.53,0.85,1.27)\ (0.55,0.87,1.27)\ (0.52,0.85,1.27)\ (0.31\ 0.\ 64,1.33)\ (0.49,0.79,1.11)\ (0.2,0.63,2.12)\ 0.77\right]$$

$G^{-} = [0.42\ (0,0.21,1.27)\ (0,0,0.63)\ (0,0.21,0.63)\ (0,0,0.33)\ (0,0,0.28)\ (0,0.32,1.41)\ 0.23]$

Afterwards, we calculate and rank S_i, R_i *and* Q_i in Table 3. Finally, the compromised alternative is determined. Since $A_{(1)}$ satisfies the conditions 1 and 2, $A_{(1)}$ is considered as the optimal alternative with the minimum Q_i.

4. Conclusion

This paper carries out an energy-efficient study on energy-efficient scheme selection by utilization of VIKOR. Besides, an empirical example is given to illustrate the process. The application would provide practical guidance optimal selection for construction techniques of certain energy-efficient members.

Table 2 Normalized evaluation table among four retrofitting schemes with heterogeneous attributes

Schemes	(C_{11})	(C_{21})	(C_{22})	(C_{23})	(C_{31})	(C_{32})	(C_{33})	(C_{42})
1	0.43	(0.18,0.43,0.95)	(0.18, 0.44, 0.95)	(0,0.21,0.63)	(0.15,0.43,1.00)	(0,0,0.28)	(0,0.32, 1.41)	0.77
2	0.47	(0,0.21,0.63)	(0, 0.22,0.63)	(0, 0.21, 0.63)	(0.31, 0.64, 1.33)	(0,0.20, 0.56)	(0.20,0.63,2.12)	0.47
3	0.65	(0.53, 0.85, 1.27)	(0.55, 0.87, 1.27)	(0.52, 0.85, 1.27)	(0.31, 0.64, 1.33)	(0.33,0.59, 1.11)	(0.20, 0.63,2.12)	0.23
4	0.42	(0,0.21,0.63)	(0,0, 0.32)	(0.17, 0.43, 0.95)	(0, 0, 0.33)	(0.49, 0.79,1.11)	(0,0.32,1.41)	0.34

Table 3 Value of S_i, R_i *and* Q_i

Scheme No.	S_i	R_i	Q_i	rank
1	0.6263	0.3234	0.7564	3
2	0.5933	0.2646	0.5004	2
3	0.2258	0.2103	0	1
4	0.8638	0.3381	1	4

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