Multi-criteria energy saving measures evaluation at the organizational and technological design stage

S H Bayramukov¹, Z N Dolaeva¹, T A Khezhev ²

¹North-caucasian state academy, 36b, Stavropolskaya str., Cherkessk, 369000, Russia
²Kabardino-balkarian state university named after h.m. berbekov, 173b, Chernyshevsky str., 360004, Nalchik, Russia

E-mail: salis_pochta@mail.ru

Abstract. The article is aimed at showing that for the organizational and technological solutions optimal choice when designing a construction object, it is necessary to take into account energy saving factors. The criteria importance assessment for energy-saving measures at the construction organization project design stage is given. The procedure for using the pairwise comparisons matrix allows to perform an optimal search for energy-saving measures, which will lead to the effective organizational and technological solutions choice at the design stage.

Introduction

The measures priority evaluation in terms of the most rational energy consumption reduction at the construction site is an urgent task in the construction industry. It is necessary to conduct a multi-criteria analysis of this issue at separate stages of organizational and technological design. When optimizing the work organization on the construction site and adjusting this process, a number of factors and criteria for their evaluation need to be considered. The following criteria were chosen as the main criteria:

- $K_1$ – the federal regulatory documents requirements achievement;
- $K_2$ – automation speed and the possibility;
- $K_3$ – the applying possibility to the objects of various purposes;
- $K_4$ – application possibility in various climatic conditions;
- $K_5$ – additional labor costs;
- $K_6$ – achieving minimization of financial resources [1,2].

Methods

Taking into account the research results on various types of energy consumers in the construction industry at the project construction organization stage, the energy saving measures ranking according to their importance has been developed [3].

Table 1. Energy saving measures ranking at the stage of the construction organization project (COP)

| Energy Saving Events (ESE)                          | Rank significance |
|----------------------------------------------------|-------------------|
| ESE1 Optimization of design solutions for the machines, mechanisms, equipment selection | 1                 |
The design optimization refers to the design solutions various variants development (variant design) and the selection of the optimal one (Table 1) [1, 4].

The event importance measure values are determined by the formula:

\[ V_i = \frac{2 \cdot (n - i + 1)}{n \cdot (n+1)} \cdot 100, \quad (1) \]

where \( n \) is the number of events;
\( i \) – defines the event rank [1, 5].

\[ V_1 = 28,57; \ V_2 = 23,81; \ V_3 = 19,05; \ V_4 = 14,29; \ V_5 = 9,52; \ V_6 = 4,76. \]

It is necessary to make paired comparisons for the events under consideration according to the formula:

\[ s_{ij} = \frac{V_i}{V_j}, \quad (2) \]

Matrix of energy-saving measures pairwise comparisons at the COP stage:

\[
S = \begin{pmatrix}
1 & 1,2 & 1,5 & 2 & 3 & 6 \\
0,83 & 1 & 1,25 & 1,67 & 2,5 & 5 \\
0,67 & 0,8 & 1 & 1,33 & 2 & 4 \\
0,5 & 0,6 & 0,75 & 1 & 1,5 & 3 \\
0,33 & 0,4 & 0,5 & 0,67 & 1 & 2 \\
0,17 & 0,2 & 0,25 & 0,33 & 0,5 & 1
\end{pmatrix}
\]

We determine the priorities vector \( P = \{p_1, p_2, \ldots, p_n\} \), using the formula:

\[ p_i = \sqrt[n]{\prod_{j=1}^{n} s_{ij}}, \quad (3) \]

\[ P = \{2,004; 1,67; 1,336; 1,002; 0,668; 0,334\}. \]

Let us normalize the vector elements using the formula:
Next, we perform the ranking of criteria for each energy saving measure at the COP stage. Criteria Ranking Results \( K = \{K_1; K_2; K_3; K_4; K_5\} \) for the energy-saving event “Optimization of design solutions for the machines, mechanisms, equipment selection” (ESE1): \( K = \{5;4;1;2;3;6\} \).

Let us define the importance values of each criteria under consideration by the formula (1):

\[
V_{1\rightarrow ESE1} = \frac{2 \cdot (6 - 5 + 1)}{6 \cdot (6 + 1)} \cdot 100 = 9.52; \quad V_{2\rightarrow ESE1} = 14.29; \quad V_{3\rightarrow ESE1} = 28.57; \\
V_{4\rightarrow ESE1} = 23.81; \quad V_{5\rightarrow ESE1} = 19.05; \quad V_{6\rightarrow ESE1} = 4.76.
\]

We create a pairwise comparison matrix \( S_{ESE1} \) for the evaluation criteria ESE1 event in accordance with the expression (2):

\[
S_{ESE1} = \begin{bmatrix}
1 & 0.67 & 0.33 & 0.4 & 0.5 & 2 \\
1.5 & 1 & 0.5 & 0.6 & 0.75 & 3 \\
3 & 2 & 1 & 1.2 & 1.5 & 6 \\
2.5 & 1.7 & 0.83 & 1 & 1.25 & 5 \\
2 & 1.33 & 0.67 & 0.8 & 1 & 4 \\
0.5 & 0.33 & 0.17 & 0.2 & 0.25 & 1
\end{bmatrix}.
\]

Let us determine the priorities vector \( P = \{p_1, p_2, \ldots, p_n\} \), elements of which are calculated by the formula (3), where \( n=6 \).

\[
p_i' = \frac{p_i}{\sum_{j=1}^{n} p_j}, \quad P' = \{0.286;0.238;0.19;0.143;0.095;0.048\}.
\]

Next, we perform the criteria ranking for the energy-saving event “Optimization of design methods and methods to ensure the construction and installation works quality” (ESE2): \( K = \{2;1;4;5;6;3\} \).

Let us define the importance values of each criteria under consideration by the formula (1):

\[
V_{1\rightarrow ESE2} = \frac{2 \cdot (6 - 2 + 1)}{6 \cdot (6 + 1)} \cdot 100 = 23.81; \quad V_{2\rightarrow ESE2} = 28.57; \quad V_{3\rightarrow ESE2} = 14.29; \\
V_{4\rightarrow ESE2} = 9.52; \quad V_{5\rightarrow ESE2} = 4.76; \quad V_{6\rightarrow ESE2} = 19.05.
\]

We create a pairwise comparison matrix \( S_{ESE2} \) for measure ESE2 for the evaluation criteria in accordance with the expression (2).
Let us determine the priorities vector $P = \{p_1, p_2, ..., p_6\}$, elements of which are calculated by the formula (3), where $n=6$:

$$P_{ESE2} = \{1.67; 2; 1; 0.67; 0.33; 1.34\}$$

We normalize the vector elements using the formula (4):

$$P' = \{0.24; 0.29; 0.14; 0.1; 0.05; 0.19\}.$$  

Next, we perform the criteria ranking for the energy-saving event “The construction site engineering design optimization” (ESE3): $K = \{1; 3; 2; 5; 6; 4\}$. 

Let us define the importance values of each criteria under consideration by the formula (1):

$$V_{1\rightarrow ESE3} = \frac{2 \cdot (6-1+1)}{5 \cdot (6+1)} \cdot 100 = 28.57; \quad V_{2\rightarrow ESE3} = 19.05; \quad V_{3\rightarrow ESE3} = 23.81; \quad V_{4\rightarrow ESE3} = 9.52; \quad V_{5\rightarrow ESE3} = 4.76; \quad V_{6\rightarrow ESE3} = 14.29.$$  

We create a pairwise comparison matrix $S_{ESE3}$ for measure ESE3 for the evaluation criteria in accordance with the expression (2):

$$S_{ESE3} = \begin{pmatrix}
1 & 1.5 & 1.2 & 3 & 6 & 2 \\
0.67 & 1 & 0.8 & 2 & 4 & 1.33 \\
0.83 & 1.25 & 1 & 2.5 & 5 & 1.67 \\
0.33 & 0.5 & 0.4 & 1 & 2 & 0.67 \\
0.17 & 0.25 & 0.2 & 0.5 & 1 & 0.33 \\
0.5 & 0.75 & 0.6 & 1.5 & 3 & 1
\end{pmatrix}$$

Let us determine the priorities vector $P = \{p_1, p_2, ..., p_6\}$, elements of which are calculated by the formula (3), where $n=6$:

$$P_{ESE3} = \{2; 1.34; 1.67; 0.67; 0.33; 1\}$$

We normalize the vector elements using the formula (4):

$$P' = \{0.29; 0.19; 0.24; 0.1; 0.05; 0.14\}.$$  

Next, we perform the criteria ranking for the energy-saving event “The industrial life builders’ organization design optimization” (ESE4): $K = \{3; 5; 1; 2; 6; 4\}$. [1]  

Let us define the importance values of each criteria under consideration by the formula (1):
\[ V_{1 \rightarrow ESE4} = \frac{2 \cdot (6 - 3 + 1)}{6 \cdot (6 + 1)} \cdot 100 = 19.05; \quad V_{2 \rightarrow ESE4} = 9.52; \quad V_{3 \rightarrow ESE4} = 28.57; \]
\[ V_{4 \rightarrow ESE4} = 23.81; \quad V_{5 \rightarrow ESE4} = 4.76; \quad V_{6 \rightarrow ESE4} = 14.29. \]

We create a pairwise comparison matrix \( S_{ESE4} \) for measure ESE4 for the evaluation criteria in accordance with the expression (2).

\[
S_{ESE4} = \begin{bmatrix}
1 & 2 & 0.67 & 0.8 & 4 & 1.33 \\
0.5 & 1 & 0.33 & 0.4 & 2 & 0.67 \\
1.5 & 3 & 1 & 1.2 & 6 & 2 \\
1.25 & 2.5 & 0.83 & 1 & 5 & 1.67 \\
0.25 & 0.5 & 0.17 & 0.2 & 1 & 0.33 \\
0.75 & 1.5 & 0.5 & 0.6 & 3 & 1
\end{bmatrix}
\]

Let us determine the priorities vector \( P = \{ p_1, p_2, \ldots, p_n \} \), elements of which are calculated by the formula (3), where \( n = 6 \):

\[ P_{ESE4} = \{1.34; 0.67; 2; 1.67; 0.33; 1\} \]

We normalize the vector elements using the formula (4):

\[ P' = \{0.19; 0.1; 0.29; 0.24; 0.05; 0.14\}. \]

Next, we perform the criteria ranking for the energy-saving event “Fuel and energy resources consumption analysis at the facilities-analogues” (ESE5): \( K = \{2; 3; 1; 4; 6; 5\} \).

Let us define the importance values of each criteria under consideration by the formula (1):

\[ V_{1 \rightarrow ESE5} = \frac{2 \cdot (6 - 2 + 1)}{6 \cdot (6 + 1)} \cdot 100 = 23.81; \quad V_{2 \rightarrow ESE5} = 19.05; \quad V_{3 \rightarrow ESE5} = 28.57; \]
\[ V_{4 \rightarrow ESE5} = 14.29; \quad V_{5 \rightarrow ESE5} = 4.76; \quad V_{6 \rightarrow ESE5} = 9.52. \]

We create a pairwise comparison matrix \( S_{ESE5} \) for measure ESE5 for the evaluation criteria in accordance with the expression (2).

\[
S_{ESE5} = \begin{bmatrix}
1 & 1.25 & 0.83 & 1.67 & 5 & 2.5 \\
0.8 & 1 & 0.67 & 1.33 & 4 & 2 \\
1.2 & 1.5 & 1 & 2 & 6 & 3 \\
0.6 & 0.75 & 0.5 & 1 & 3 & 1.5 \\
0.2 & 0.25 & 0.17 & 0.33 & 1 & 0.5 \\
0.4 & 0.5 & 0.33 & 0.67 & 2 & 1
\end{bmatrix}
\]
Let us determine the priorities vector \( P = \{ p_1, p_2, ..., p_n \} \), elements of which are calculated by the formula (3), where \( n=6 \):

\[
P_{ESE6} = \{1,67;1,34;2;1;0,33;0,67\}
\]

We normalize the vector elements using the formula (4):

\[
P' = \{0,24;0,19;0,29;0,14;0,05;0,1\}.
\]

Next, we perform the criteria ranking for the energy-saving event “Fuel and energy resources consumption predicted values determination (according to the required capacity) on the production and household standards basis” (ESE6): \( K = \{3;4;1;2;6;5\} \). [6-8]

Let us define the importance values of each criteria under consideration by the formula (1):

\[
V_{i \rightarrow ESE6} = \frac{2 \cdot (6 - 3 + 1)}{6 \cdot (6 + 1)} \cdot 100 = 19,04; \quad V_{2 \rightarrow ESE6} = 14,29; \quad V_{3 \rightarrow ESE6} = 28,57; \\
V_{4 \rightarrow ESE6} = 23,81; \quad V_{5 \rightarrow ESE6} = 4,76; \quad V_{6 \rightarrow ESE6} = 9,52.
\]

We create a pairwise comparison matrix \( S_{ESE6} \) for measure ESE6 for the evaluation criteria in accordance with the expression (2).

\[
S_{ESE6} = \begin{pmatrix}
1 & 1,33 & 0,67 & 0,8 & 4 & 2 \\
0,75 & 1 & 0,5 & 0,6 & 3 & 1,5 \\
1,5 & 2 & 1 & 1,2 & 6 & 3 \\
1,25 & 1,67 & 0,83 & 1 & 5 & 2,5 \\
0,25 & 0,33 & 0,17 & 0,2 & 1 & 0,5 \\
0,5 & 0,67 & 0,33 & 0,4 & 2 & 1
\end{pmatrix}
\]

Let us determine the priorities vector \( P = \{ p_1, p_2, ..., p_n \} \), elements of which are calculated by the formula (3), where \( n=6 \):

\[
P_{ESE6} = \{1,34;1;2;1,67;0,33;1,67\}
\]

We normalize the vector elements using the formula (4):

\[
P' = \{0,19;0,14;0,29;0,24;0,05;0,24\}.
\]

Results and discussion

Figure 1 shows a petal diagram in which the evaluation criteria importance indicators for energy-saving measures at the COP stage are presented [8]. The most significant criterion for event ESE1 is K3- ESE 1, for ESE 2 it is K2- ESE 2, for ESE 3 it is K1- ESE 3, for ESE 4 it is K3- ESE 4, for ESE 5 it is K3- ESE 5, for ESE 6 it is K3- ESE 6.
Summary
1. The criteria importance indicators for energy-saving measures at the construction organization project design stage are estimated.
2. The procedure for using the pairwise comparisons matrix allows to perform an optimal search for energy-saving measures, which is of considerable interest when choosing the best solutions at the construction organization project design stage.
3. At the COP development stage, the measures to optimize the design decisions when selecting machines, mechanisms, equipment and designing methods and means for ensuring the construction and installation works quality and intensifying technological processes received the greatest significance.

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