SELECTION OF THE EFFECTIVE DWELLING HOUSE WALLS BY APPLYING ATTRIBUTES VALUES DETERMINED AT INTERVALS

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Received 08 Jan 2008, accepted 10 Apr 2008

1. Introduction

The number of residential houses in Lithuania is increasing every year. For a non-insulated building, which could be situated in different climate conditions, these particular heat-losses can vary between 10–20 % (through floors), 25–30 % (through outer walls), 25–30 % (through attic slabs and roof plates) and 30–40 % (through windows) of the total heat loss. In Lithuania nearly a half of all heating losses are caused by low quality walls (Fig. 1). Therefore the thorough and professional selection of an optimal building thermal insulation system represents one of the most important technical and economical goals for both the Designer and the Investor. The selection of an effective variant of external building walls among a vast number of alternatives is an important problem in project management.

Introduction of various thermal insulation systems in the contemporary civil engineering practice is caused by the major expansion of energy resource prices at the world market. As a result, there is a growing need for significant heat-loss reduction during exploitation of buildings, which as a rule could be realized using more or less effective building systems to prevent heat loss through outer walls. Building and exploitation expenses depend on how effective the external wall solution has been chosen. It should be done by establishing the requirements and aims till the expiry of a building. The benefit obtained from effectively heating up the external walls could be defined by indices as shown in Fig. 2. The selection of a building’s external walls (Fig. 3) is a decision characterized by multiple attributes. Clients want to minimize the likely costs of the project, but they also want to achieve highest acceptable quality standards as well as to satisfy technological, architectural, and comfort requirements. Other participants of construction process (e.g. designer, contractor) are interested in maximizing profits; they are also concerned with other attributes such as company growth, market share, and the state institutions’ interests.

All decisions involve choosing one from several alternatives. Multiple attribute optimization is a process of determining a feasible solution for the decision maker according to the established attributes (e.g. a set of the quantitative and qualitative attributes). Multiple attribute methods are available for evaluation of external walls alternatives. In this paper, the authors present a methodology that allows decision maker to reach a decision by designing alternatives of a building’s external walls and to evaluate attributes both qualitative and quantitative contained in the process.
2. Multi-layered external walls

Facade structures of residential and business buildings are facing following demands:
- Ability to function as bearing or self-bearing walls;
- Possession of high thermal insulation properties;
- Sound insulation;
- Overall hygrothermal performance;
- Frost resistance;
- Air tightness;
- Vapour permeability;
- Sufficient light-weightiness;
- Ecological cleanliness;
- Satisfactory fireproofing;
- Durability.

There is usually not enough attention paid to the fact that multi-layered facade structures are made as composite sections of heterogeneous materials with different physical-mechanical properties, such as:
- Expansion and shrinkage coefficients;
- Compressive and tensile strengths;
- Adhesion properties;
- Behaviour under different types of wind load;
- Behaviour under ultraviolet radiation exposure;
- Difference between strain values in adjacent walls with significant temperature;
- Variation due to different sun exposure and colour of the final facade coating;
- Difference in aging properties of each composite during exploitation;
- Air and vapour permeability values.

Cost-effectiveness in application of multi-layer external walls in Civil engineering – is the most interesting issue for the Investor. Without getting into all the inferior physical, thermo-technical and ecological properties (not to mention the poor durability) of the usually applied facade structures (bricks or blocks insulated with mineral wool or Styrofoam and coated with mineral polymer-cement plaster over glass-fibre net or simply protected with facade bricks), let us analyze the indisputable cost-effectiveness, even possible profit for the Investor calculated per meter of a facade wall built using multi-layer external walls.

For multilayer walls, three basic material configurations were considered: insulation either inside or outside the massive layer, and insulation located between two massive layers. The results of extensive parametric analysis have shown explicitly that walls with the insulation outside always performed better than those with the insulation inside:
- The system covers the entire building wall (except windows and doors). Thus, multi-layered exterior wall systems provide an insulation layer over potential thermal bridges such as wall studs and columns and floor-wall junctions.
- Because the entire exterior wall is covered, building air tightness is improved.
• Because insulation is placed on the building exterior, the building structure is kept warm; this minimizes thermal expansion and contraction.

• Finally, if properly installed, the system avoids a build-up of moisture in the building cladding.

Model of problem

The aim of this investigation is to create a technique for the choice and selection of different and effective versions of the external walls construction. The purpose is to be achieved by using various indicators of effectiveness, which have different dimensions, different significances as well as different directions of optimization (Kendall 1970; Zavadskas 1987; Šaparauskas and Turskis 2006; Kaklauskas et al. 2006).

The main steps of multiple attributes decision-making are as follows:

- Establishing system evaluation attributes that relate system capabilities to goals;
- Developing alternative systems for attaining the goals (generating alternatives);
- Evaluating alternatives in terms of attributes (the values of the attribute functions);
- Applying a normative multiple attributes analysis method;
- Accepting one alternative as “optimal” (preferred);
- If the final solution is not accepted, gather new information and go into the next iteration of multiple attributes optimization.

AlTERNATIvES OF EXTERNAL WALL CONSTRUCTION ARE BEING FORMED BY USING VARIOUS MATERIALS WITH THERMAL INSULATION AS WELL AS DIFFERENT KINDS OF DECORATION MASONRY AND THIN DAUB LAYER. A SYSTEM OF INDICATORS FOR WALL CONSTRUCTION EFFECTIVENESS’ EVALUATION HAS BEEN ESTABLISHED (Fig. 3).

The solving of each multi-attribute problem begins with constructing of decision-making matrix (Fig. 4).

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Attributes</th>
<th>C1</th>
<th>C2</th>
<th>...</th>
<th>Cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>a11</td>
<td>a12</td>
<td>...</td>
<td>...</td>
<td>a1m</td>
</tr>
<tr>
<td>A2</td>
<td>a21</td>
<td>a22</td>
<td>...</td>
<td>...</td>
<td>a2m</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>An</td>
<td>an1</td>
<td>an2</td>
<td>...</td>
<td>...</td>
<td>ann</td>
</tr>
</tbody>
</table>

Fig. 4. Decision-making matrix for multi-attribute decision-making problems

In this matrix (Fig. 4) values of the attributes $a_{ij}$ may be:

- Real numbers;
- Intervals;
- Probability distributions;
- Possibility distributions;
- Qualitative labels.

The problem may be:

- Choice—Select the most appropriate (best) alternative;
- Ranking—Draw a complete order of the alternatives from the best to the worst ones;
- Sorting—Select the best $k$ alternatives from the list of $n-k$.

When we consider a discrete set of alternatives described by some attributes, there are three different types of analyses that can be performed in order to provide a significant support to decision-makers:

- Ensure that the decision-maker follows a “rational” behaviour (Normative option) – Value functions, Utility theory, distance to the Ideal;
- Give some advice based on reasonable (but not indisputable) rules – The French School.
- Find the preferred solution from the partial decision hypothesis – Interactive methods.

Multiple attributes decision aid provides several powerful and effective tools (Hwang and Yoon 1981; Figueira et al. 2005) for confronting sorting problems. There can be used very simplified techniques for the evaluation of a decision support methods base including methods such as the Simple Additive Weighting — SAW; TOPSIS — Technique for Order Preference by Similarity to Ideal Solution (Hwang and Yoon 1981; Zavadskas 1987; Antuchevičienė 2005; Chang et al. 2005) and methods of the ELECTRE (Elimination and Choice Translating Reality) family, such as ELECTRE and UTA (UTilités Additives, cf.). A variant of the UTA method is the UTADIS method (Utilités Additives Discriminantes). The Preference Ranking Organisation MeTHod for Enrichment Evaluations (PROMETHEE) can be applied to the solution too.


The task of the selection of different versions of the effective external walls construction is solved by applying COPRAS method. COPRAS (technique for order preference by similarity to an ideal solution) method is presented by Zavadskas and Kaklauskas (Zavadskas et al. 1994; Zavadskas and Kaklauskas 1996). The COPRAS method determines a solution with the ratio to the ideal solution and the ratio with the ideal-worst solution.

3. Ranking of the alternatives applying COPRAS method

3.1. Determination of the attributes weights

In order to select the best alternative, it is necessary, to have formed the decision matrix, to perform the project's multiple attributes analysis. MCDM refers to making preference decisions on the alternatives in terms of multiple attributes. Typically, each alternative is evaluated on the established set/system of attributes.
To determine the weights of the attributes, the expert’s judgment method is applied (Kendall 1970) which has been successfully used in research by the authors since 1987 (Zavadskas 1987; Zavadskas and Kaklauskas 1996; Kaklauskas et al. 2006; Zavadskas and Vilutienė 2006; Bardauskienė 2007). In order to establish the importance indicators, a survey has been carried out and 39 experts have been questioned. These experts, basing their answers on their knowledge, experience and intuition, had to rate indicators of effectiveness starting with the most important ones. The rating was done on a scale from 1 to 5, where 5 meant “very important” and 1 “not important at all”. The importance of indicators was established according to the rating methods (Zavadskas 1987) of these experts and also demonstrated the priorities of the user (owner).

The significance of the attributes obtained by this method are presented in Table 1.

3.2. A method of multiple criteria complex proportional assessment – COPRAS

In order to evaluate the overall efficiency of a project it is necessary to identify selection attributes, to assess information, relating to these attributes, and to develop methods for evaluating the attributes to meet the participant’s needs. Decision analysis is concerned with the situation in which a decision-maker has to choose among several alternatives by considering a common set of attributes. The COPRAS method (Zavadskas et al. 1994; Zavadskas and Kaklauskas 1996) presented here uses a stepwise ranking and evaluating procedure of the alternatives in terms of significance and utility degree. This method was applied to solution of various problems in construction, property management, economics etc. (Zavadskas et al. 1994; Zavadskas and Kaklauskas 1996; Andruškevičius 2005; Malinauskas and Kalibatas 2005; Žiogas and Juociūnas 2005; Kaklauskas et al. 2006; Viteikienė 2006; Zavadskas and Antučiūnienė 2006; Zavadskas et al. 2007a; Viteikienė and Zavadskas 2007; Kaklauskas et al. 2007).

The procedure of the COPRAS method consists of the steps as shown in Fig. 5.

3.3. A method of multiple criteria complex proportional assessment with values determined in intervals – COPRAS-G

In many decisions the consequences of the alternative courses of action cannot be predicted with certainty. A company considering the launch of a new product will be, while an investor on the stock market will generally be unsure about the returns which will be generated, if a particular investment is chosen.

We will first outline a method which assumes that the decision maker is unable, or unwilling, to estimate probabilities for the outcomes of the decision and which, in consequence, makes extremely pessimistic assumptions about these outcomes.

Finally, we will broaden the discussion to consider problems involving both uncertainty and more than one attribute. As we saw in problems involving multiple attributes are often too large for a decision-maker to comprehend in their entirety.

The idea to COPRAS-G method comes from real conditions of decision-making and from applications of the Grey systems theory. This theory was originated by Deng (1982) study of the relation degree among various attributes in an MCDM problem. In 1988 Deng (1988a) presented grey decision-making systems. Grey relational analysis possesses advantages of Deng (1988b): it involves simple calculations; it requires smaller samples; a typical distribution of samples is not needed; the quantified outcomes from the grey relational grade do not result in contradictory conclusions about the qualitative analysis; and the grey relational grade model is a transfer functional model that is effective in dealing with discrete data.

It is useful mathematically when dealing with a system with a limited information. According to this theory, a system whose internal information is completely known is called a white system. On the contrary, a system is defines as a black system if one cannot obtain any information and characteristics about the system. Grey space is thus defined as a system defined between the white and black systems. The grey system has been applied in many fields, such as economics, agriculture, geography, weather, earthquakes, science etc. For example, Wending et al. (2002), Wu and Chang (2003), Du and Sheen (2005) applied the grey model to solution of problems. Haq and Kannan (2007) developed a hybrid normalised multi-criteria decision-making model for evaluating and selecting the vendor using Analytical Hierarchy Process and Fuzzy Analytical Hierarchy Process and an integrated approach of Grey Relational Analysis to a Supply Chain model. Linet et al. (2008) presents an illustrative example of subcontractor selection by applying grey TOPSIS method.

The procedure of the COPRAS method with attributes values expressed in interval COPRAS-G includes the following steps:

1. Selection of the available set of the most important attributes, which describes alternatives;

2. Preparing the decision-making matrix $X$:

$$X = \begin{bmatrix}
[w_{11}; b_{11}] & [w_{12}; b_{12}] & \ldots & [w_{1m}; b_{1m}] \\
[w_{21}; b_{21}] & [w_{22}; b_{22}] & \ldots & [w_{2m}; b_{2m}] \\
\vdots & \vdots & \ddots & \vdots \\
[w_{n1}; b_{n1}] & [w_{n2}; b_{n2}] & \ldots & [w_{nm}; b_{nm}]
\end{bmatrix}, \quad j = 1, n; i = 1, m \quad (1)$$

where $w_{ij}$ – the least value – lower limit, $b_{ij}$ – the biggest value – upper limit.

3. Determining weights of the attributes $q_j$.

4. Normalization of the decision-making matrix $X$. The normalized values of this matrix (Hwang and Yoon 1981; Zavadskas 1987; Migilinskas and Ustinovičius 2007) are calculated as:
In formula (2) \( w_{ij} \) is the lower value of the \( j \)-th attribute in the \( i \)-th alternative of a solution; \( b_{ij} \) – the upper value of the \( j \) attribute in the \( i \) alternative of a solution; \( m \) – the number of attributes; \( n \) – the number of the alternatives compared.

After this step we have normalized decision-making matrix:

\[
\begin{bmatrix}
\frac{w_{11}}{b_{11}} & \frac{w_{12}}{b_{12}} & \ldots & \frac{w_{1m}}{b_{1m}} \\
\frac{w_{21}}{b_{21}} & \frac{w_{22}}{b_{22}} & \ldots & \frac{w_{2m}}{b_{2m}} \\
\vdots & \vdots & \ddots & \vdots \\
\frac{w_{n1}}{b_{n1}} & \frac{w_{n2}}{b_{n2}} & \ldots & \frac{w_{nm}}{b_{nm}}
\end{bmatrix}
\]  

(3)

5. Calculation of the weighted normalized decision matrix \( \bar{X} \). The weighted normalized values \( \bar{w}_{ij} \) are calculated as

\[
\bar{w}_{ij} = w_{ij} \cdot q_j; \\
\bar{b}_{ij} = b_{ij} \cdot q_j.
\]  

In formula (4), \( q_j \) is significance (weight) of the \( j \)-th attribute.

After this step we have weighted normalized decision-making matrix:

\[
\begin{bmatrix}
\bar{w}_{11} & \bar{w}_{12} & \ldots & \bar{w}_{1m} \\
\bar{w}_{21} & \bar{w}_{22} & \ldots & \bar{w}_{2m} \\
\vdots & \vdots & \ddots & \vdots \\
\bar{w}_{n1} & \bar{w}_{n2} & \ldots & \bar{w}_{nm}
\end{bmatrix}
\]  

(5)

6. Sums \( P_j \) of attributes values which larger values are more preferable (optimization direction is maximization) calculation for each alternative (line of the decision-making matrix):

\[
P_j = \frac{1}{2} \sum_{i=1}^{k} (\bar{w}_{ij} + \bar{b}_{ij}).
\]  

In formula (6), \( k \) is number of attributes which must be maximised (it is assumed that in the decision-making matrix columns first of all are placed attributes with optimization direction maximum and the ones with optimization direction minimum are placed after).

7. Sums \( \bar{R}_j \) of attributes values which smaller values are more preferable (optimization direction is minimization) calculation for each alternative (line of the decision-making matrix):

\[
\bar{R}_j = \frac{1}{2} \sum_{i=k+1}^{m} (\bar{w}_{ij} + \bar{b}_{ij}); \quad i = k, m.
\]  

(7)

In formula (7), \( m - k \) is number of attributes which must be minimized.

8. Determining the minimal value of \( \bar{R}_j \):

\[
\bar{R}_{\min} = \min \{ \bar{R}_j \}; \quad j = \bar{j}, m.
\]  

(8)

9. Calculation of the relative weight of each alternative \( Q_j \):
The analysis of all of these requirements can be performed according to the factors:
- Quality of components;
- Design level;
- Work execution level;
- Indoor environment;
- Outdoor environment;
- In-use conditions;
- Maintenance levels.

Optimization directions of selected attributes are as follows:
- $x_1$ optimization direction $\rightarrow \max$;
- $x_2, x_3, x_4, x_5$ optimization direction $\rightarrow \min$.

Respondents were from one of several kinds of organizations (owners, designers, contractors, scientists).

According to thermal transmittance data, alternative 3 was first in the list of priorities. According to durability of walls data, alternative 1 (is equal to 2 and 3) was first in the list of priorities, while alternative 4 was the fourth. According to weight of $m^2$ walls data, alternative 4 was first in the list of priorities, while alternative 2 was the fourth. According to human expenditures data, alternative 4 was first in the list of priorities, while Alternative 1 was the fourth.

The final choice of external walls was made by COPRAS-G method. In Table 2 the normalized weighted decision-making matrix is given. On the basis of the efficiency priority of alternatives, a rank $R_j$ of each alternative is established. According to the calculation results, alternative 1 is the best one (Table 3). The first alternative is also the best in terms of its utility degree that equals 100 %. The second alternative with utility degree 96.9 % has rank 3. The third alternative with utility degree 99.7 % has rank 2. The fourth alternative with the utility degree 82.1 % is the worst and has rank 4. Vector of optimality criterion values $N_j$ is:

$$N_j = [100; 96.9; 99.7; 82.1].$$

According to the $N_j$ the alternatives rank as follows: $A_1 > A_2 > A_3 > A_4$.

5. Conclusions

In real life multi-attribute modelling of multi-alternative assessment problems some attribute values, which deals with the future, must be expressed in intervals.

For this reason a new method of multiple criteria complex proportional assessment with values determined in intervals – COPRAS-G is developed.

By the analysis of the problem solution results it has been established that silicate brick masonry walls with outer finishing layer are more preferable than three another ones under investigation.
Table 1. Initial decision-making matrix with values expressed in intervals

<table>
<thead>
<tr>
<th>Alternative No.</th>
<th>Durability of walls (cycles)</th>
<th>Thermal transmittance (W/m·K)</th>
<th>The estimated cost of m² walls, (LTL)</th>
<th>Weight of m² walls, (kg)</th>
<th>Human expenditures, (hour/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimization direction</td>
<td>max</td>
<td>min</td>
<td>min</td>
<td>min</td>
<td>min</td>
</tr>
<tr>
<td>Attribute weight q</td>
<td>x₁</td>
<td>x₂</td>
<td>x₃</td>
<td>x₄</td>
<td>x₅</td>
</tr>
<tr>
<td>w₁, b₁</td>
<td>w₂, b₂</td>
<td>w₃, b₃</td>
<td>w₄, b₄</td>
<td>w₅, b₅</td>
<td></td>
</tr>
<tr>
<td>Silicate brick masonry with masonry outer finishing layer</td>
<td>75</td>
<td>100</td>
<td>0.22</td>
<td>0.25</td>
<td>72.08</td>
</tr>
<tr>
<td>Ceramic brick masonry with masonry outer finishing layer</td>
<td>75</td>
<td>100</td>
<td>0.22</td>
<td>0.25</td>
<td>89.01</td>
</tr>
<tr>
<td>Ceramic fenestrate brick masonry with masonry outer finishing layer</td>
<td>75</td>
<td>100</td>
<td>0.21</td>
<td>0.25</td>
<td>80.32</td>
</tr>
<tr>
<td>Silicate bricks masonry with outer plaster finishing layer</td>
<td>25</td>
<td>25</td>
<td>0.24</td>
<td>0.27</td>
<td>67.76</td>
</tr>
</tbody>
</table>

Table 2. Weighted normalized decision-making matrix according to a COPRAS-G method

<table>
<thead>
<tr>
<th>Alternative No.</th>
<th>Weighted normalized values of the attributes describing the compared alternatives – matrix $\hat{X}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\hat{w}_1$</td>
</tr>
<tr>
<td>1</td>
<td>0.055</td>
</tr>
<tr>
<td>2</td>
<td>0.055</td>
</tr>
<tr>
<td>3</td>
<td>0.055</td>
</tr>
<tr>
<td>4</td>
<td>0.018</td>
</tr>
</tbody>
</table>

Table 3. Decision results according to a COPRAS-G method ($R_j$ – ascending rank of alternatives. The smallest is the best)

<table>
<thead>
<tr>
<th>Alternative No</th>
<th>Total sum of maximizing normalized indices $R_j$</th>
<th>Total sum of minimizing normalized indices $P_j$</th>
<th>Alternative’s significance $Q_j$</th>
<th>Alternative’s degree of efficiency $N_j$</th>
<th>Rank $R_j$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.390</td>
<td>0.128</td>
<td>0.528</td>
<td>100</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>0.406</td>
<td>0.128</td>
<td>0.512</td>
<td>96.9</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>0.391</td>
<td>0.128</td>
<td>0.526</td>
<td>99.7</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>0.393</td>
<td>0.037</td>
<td>0.434</td>
<td>82.1</td>
<td>4</td>
</tr>
</tbody>
</table>

This model and solution results have practical and scientific interests. They allow investors to make decision concerning multiple attributes, when values of initial data are given in the intervals.

This COPRAS-G method can be applied to the solution of wide range discrete multi-attribute assessment problems in construction.

References


Santrauka


Reikšminiai žodžiai: sienos, alternatyvos, daugiatikslis parinkimas, vertinimas, COPRAS, COPRAS-G, pilkieji skaičiai.

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