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

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Abstract. The higher life quality standards, the changes of habits and new well-being requirements have led to an increase in the demand for housing. Decision-making problems in construction management often involve a complex decision-making process in which multiple requirements and conditions have to be taken into consideration simultaneously. However, not every attribute used in multidimensional scaling is equally and precisely weighted in the real world. Thus quantitative and qualitative assessments are often required to deal with uncertainty, subjective and imprecise data. The accuracy of performance measures in common multi-attribute methods is usually assumed to be accurate. Grey theory is a new technique for performing prediction, relational analysis and decision-making in many areas. This paper considers the application of grey relations methodology for defining the utility of an alternative and is proposed as a method of multiple criteria COmplex PRoportional ASsessment of alternatives with Grey relations (COPRAS-G). In this model parameters of the alternatives are determined by the grey relational grade and are expressed in intervals. A case study of assessing external walls of four alternatives was used to demonstrate the applicability and the effectiveness of the proposed approach. The results show that this method can be implemented as an effective decision aid in multi-attribute selection.

Keywords: walls, alternatives, multi-attribute, selection, COPRAS, COPRAS-G, grey number.

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.

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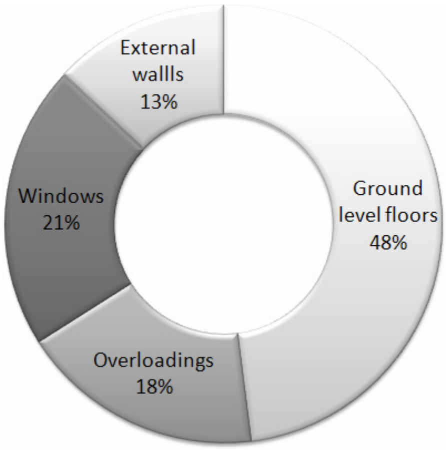


Fig. 1. Average annual losses of heat in residential buildings of Lithuania

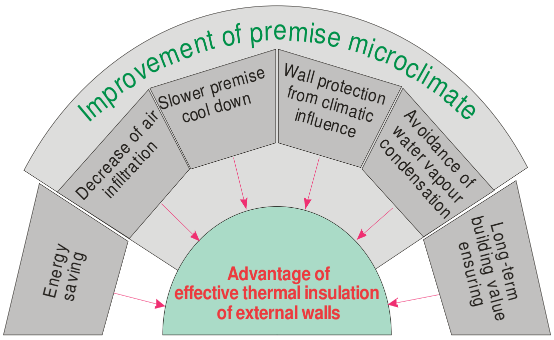
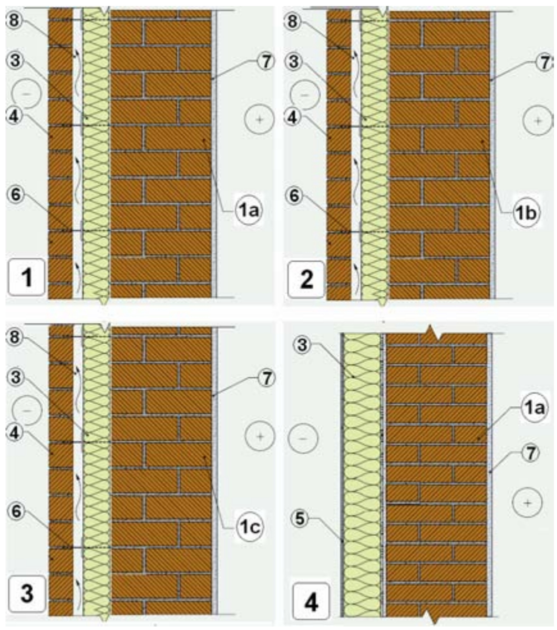


Fig. 2. Advantage of effective thermal insulation of external walls



1a – Silicate bearing brick;
1b – Ceramic bearing brick;
1c – Ceramic fenestrate;
3 – Rock wool or expanded; polystyrene;
4 – Finishing brick;
5 – Outer plaster;
6 – Wind barrier;
7 – Inner plaster;
8 – Air space (2–3 cm)

Fig. 3. Alternatives of multi-layered external walls under investigation

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; Zavadskas and Vilutiene 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).

Alternatives	Attributes			
	C_1	C_2	...	C_m
A_1	a_{11}	a_{12}	...	a_{1m}
A_2	a_{21}	a_{22}	...	a_{2m}
	...	...	...	...
A_n	a_{n1}	a_{n2}	...	a_{nm}

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.

For a more detail survey of Multi criteria decision-making methods see for applications in the construction context Zavadskas (1987), Zavadskas *et al.* (2004), Zavadskas *et al.* (2005), Kaklauskas *et al.* (2005), Peldschus and Zavadskas (2005), Antuchevičienė *et al.* (2006), Su *et al.* (2006), Šaparauskas and Turskis (2006), Turskis *et al.* (2006), Zagorskas and Turskis (2006), Zavadskas *et al.* (2006), Kalibatas *et al.* (2007), Ustinovichius *et al.* (2007), Zavadskas and Antuchevičienė (2007), Zavadskas *et al.* (2007b) and Banaitienė *et al.* (2008).

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 Juočiūnas 2005; Kaklauskas *et al.* 2006; Viteikienė 2006; Zavadskas and Antuchevičienė 2006; Zavadskas *et al*. 2007a; Viteikiene 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 a certainty. A company considering the launch of a new product will be uncertain about how successful the 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 defined 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:

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

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 $\overline{X}$. The normalized values of this matrix (Hwang and Yoon 1981; Zavadskas 1987; Migilinskas and Ustinovičius 2007) are calculated as:

$$\overline{w_{ij}} = \frac{w_{ij}}{\frac{1}{2}\left(\sum_{j=1}^{n} w_{ij} + \sum_{j=1}^{n} b_{ij}\right)} = \frac{2w_{ij}}{\sum_{j=1}^{n} w_{ij} + \sum_{j=1}^{n} b_{ij}};$$

$$\overline{b_{ij}} = \frac{b_{ij}}{\frac{1}{2}\left(\sum_{j=1}^{n} w_{ij} + \sum_{j=1}^{n} b_{ij}\right)} = \frac{2b_{ij}}{\sum_{j=1}^{n} (w_{ij} + b_{ij})}; \quad (2)$$

$i = \overline{1,n}$ *and* $j = \overline{1,m}.$

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:

$$\overline{X} = \begin{bmatrix} [\overline{w_{11}};\overline{b_{11}}] & [\overline{w_{12}};\overline{b_{12}}] & \ldots & [\overline{w_{1m}};\overline{b_{1m}}] \\ [\overline{w_{21}};\overline{b_{21}}] & [\overline{w_{21}};\overline{b_{22}}] & \ldots & [\overline{w_{2m}};\overline{b_{2m}}] \\ \vdots & \vdots & \ldots & \vdots \\ [\overline{w_{n1}};\overline{b_{n1}}] & [\overline{w_{n2}};\overline{b_{n2}}] & \ldots & [\overline{w_{nm}};\overline{b_{nm}}] \end{bmatrix}. \quad (3)$$

5. Calculation of the weighted normalized decision matrix $\hat{X}$. The weighted normalized values $\hat{x}_{ij}$ are calculated as

$$\hat{w}_{ij} = \overline{w_{ij}} \cdot q_j; \quad \hat{b}_{ij} = \overline{b_{ij}} \cdot q_j. \quad (4)$$

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

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

$$\hat{X} = \begin{bmatrix} [\hat{w}_{11};\hat{b}_{11}] & [\hat{w}_{12};\hat{b}_{12}] & \ldots & [\hat{w}_{1m};\hat{b}_{1m}] \\ [\hat{w}_{21};\hat{b}_{21}] & [\hat{w}_{21};\hat{b}_{22}] & \ldots & [\hat{w}_{2m};\hat{b}_{2m}] \\ \vdots & \vdots & \ldots & \vdots \\ [\hat{w}_{n1};\hat{b}_{n1}] & [\hat{w}_{n2};\hat{b}_{n2}] & \ldots & [\hat{w}_{nm};\hat{b}_{nm}] \end{bmatrix}. \quad (5)$$

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:

$$P_j = \frac{1}{2}\sum_{i=1}^{k}(\hat{w}_{ij} + \hat{b}_{ij}). \quad (6)$$

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).

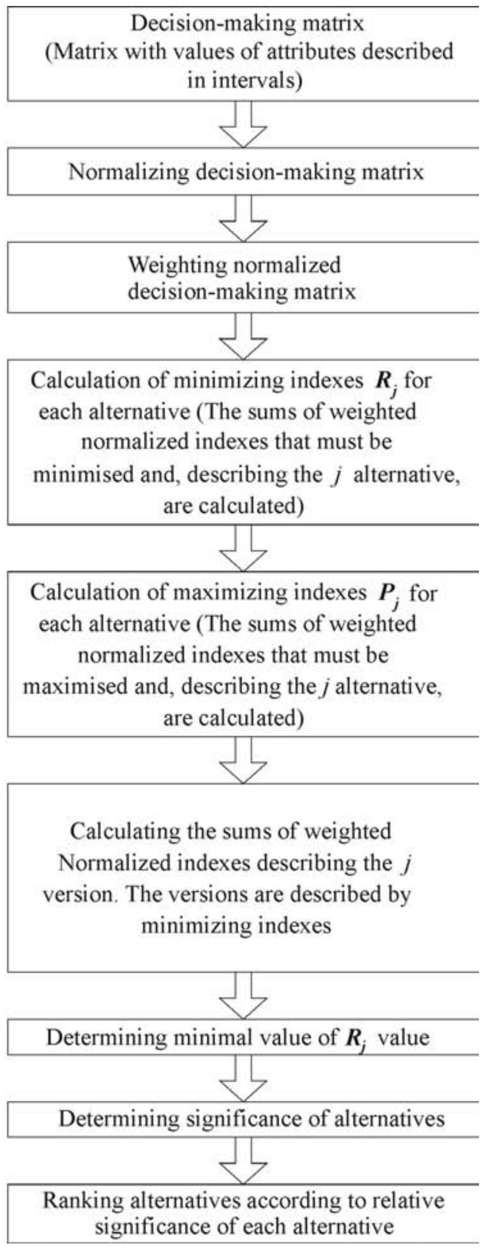


Fig. 5. Ranking of alternatives by applying COPRAS method.

7. Sums 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:

$$R_j = \frac{1}{2}\sum_{i=k+1}^{m}(\hat{w}_{ij} + \hat{b}_{ij}); \quad i = \overline{k,\ m}. \quad (7)$$

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

8. Determining the minimal value of R_j:

$$R_{\min} = \min_j R_j; \quad j = \overline{j,m}. \quad (8)$$

9. Calculation of the relative weight of each alternative Q_j:

$$Q_j = P_j + \frac{R_{\min}\sum_{j=1}^{n} R_j}{R_j \sum_{j=1}^{n} \frac{R_{\min}}{R_j}}. \quad (9)$$

Formula (9) can to be written as follows:

$$Q_j = P_j + \frac{\sum_{j=1}^{n} R_j}{R_j \sum_{j=1}^{n} \cdot \frac{1}{R_j}}. \quad (9^*)$$

10. Determination of the optimality criterion ***K***:

$$K = \max_j Q_j; \quad j = \overline{1, n}. \quad (10)$$

11. Determination of the project priority. The greater significance (relative weight of alternative) Q_j, the higher is the priority (rank) of the project. The relative significance Q_j of project *j* indicates the satisfaction degree of the needs of the project participants. In case of $Q_{\max}$, the satisfaction degree is the highest. The relative significance of other projects is less.

12. Calculation of the utility degree of each alternative. The degree of project utility is determined by comparing the analyzed projects with the best one. The values of the utility degree are from 0 % to 100 % between the worst and the best alternatives. The utility degree N_j of each alternative j is calculated as

$$N_j = \frac{Q_j}{Q_{\max}} 100\ \%, \quad (11)$$

where Q_j and $Q_{\max}$ are the significance of projects obtained from Eq. (9*).

The decision approach proposed in this section allows evaluating the direct and proportional dependence of the significance and utility degree of alternatives in a system of attributes, weights and values of the attributes.

4. Selection of the effective dwelling house walls by applying attributes values determined in intervals

The initial data of this problem are taken from Zavadskas *et al.* (2005) research work. The 39 experts were asked to prioritize the 5 attributes listed in Table 1:

- Durability of walls (frost resistance) (cycles) $x_1 - [w_{i1}; b_{i1}]$;
- Thermal transmittance (W/m·K) $x_2 - [w_{i2}; b_{i2}]$;
- The estimated cost of m^2 walls $x_3 - [w_{i3}; b_{i3}]$;
- Weight of m^2 walls (kg) $x_4 - [w_{i4}; b_{i4}]$;
- Human work expenditures (hour/m^2) $x_5 - [w_{i5}; b_{i5}]$.

Selected attributes do not cover the all important requirements of buildings. The European Council Directive 89/106/EEC has set six essential requirements:

- Mechanical resistance and stability;
- Safety in case of fire;
- Hygiene, health and environment;
- Safety in use;
- Protection against noise;
- Energy economy and heat retention.

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;
- Maintenence levels.

Optimization directions of selected attributes are as follows:

- $x_1 \xrightarrow{optimization\ direction} \max$;
- $x_2, x_3, x_4, x_5 \xrightarrow{optimization\ direction} \min$.

Respondents were from one of several kinds of organizations (owners, designers, contractors, scientists). The determination of quantitative attributes values is based on the use of analyzed projects, price-lists, specifications, reference books and recommendations.

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 $\boldsymbol{R}_j$ 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 $\boldsymbol{N}_j$ is:

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

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

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

Alternative No.	Durability of walls (cycles)		Thermal trans-mittance (W/m·K)		The estimated cost of m^2 walls, (LTL)		Weight of m^2 walls, (kg)		Human expen-ditures, (hour/m^2)	
Optimization direction	*max*		*min*		*min*		*min*		*min*	
Attribute weight q	0.21		0.33		0.26		0.09		0.11	
	x_1		x_2		x_3		x_4		x_5	
	w_1	b_1	w_2	b_2	w_3	b_3	w_4	b_4	w_5	b_5
Silicate brick masonry with masonry outer finishing layer	75	100	0.22	0.25	72.08	94.71	590	652	4.60	4.60
Ceramic brick masonry with masonry outer finishing layer	75	100	0.22	0.25	89.01	100.93	596	625	4.60	4.60
Ceramic fenestrate brick masonry with masonry outer finishing layer	75	100	0.21	0.25	80.32	96.42	581	604	4.60	4.60
Silicate bricks masonry with outer plaster finishing layer	25	25	0.24	0.27	67.76	98.10	455	479	4.55	5.01

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

Alterna-tive No.	Weighted normalized values of the attributes describing the compared alternatives – matrix $\hat{X}$									
	$\hat{w}_1$	$\hat{b}_1$	$\hat{w}_2$	$\hat{b}_2$	$\hat{w}_3$	$\hat{b}_3$	$\hat{w}_4$	$\hat{b}_4$	$\hat{w}_5$	$\hat{b}_5$
1	0.055	0.073	0.076	0.086	0.054	0.070	0.023	0.026	0.027	0.027
2	0.055	0.073	0.076	0.086	0.066	0.075	0.023	0.025	0. 027	0.027
3	0.055	0.073	0.073	0.086	0.060	0.072	0.023	0.024	0.027	0.027
4	0.018	0.018	0.083	0.093	0.050	0.073	0.018	0.019	0.027	0.030

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

Alternative No	Total sum of maximizing normalized indices R_j	Total sum of minimizing normalized indices P_j	Alternative's significance Q_j	Alternative's degree of efficiency N_j	Rank R_j
1	0.390	0.128	0.528	100	1
2	0.406	0.128	0.512	96.9	3
3	0.391	0.128	0.526	99.7	2
4	0.393	0.037	0.434	82.1	4

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.

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DAUGIABUČIŲ NAMŲ IŠORINIŲ SIENŲ EFEKTYVUMO VERTINIMAS, KAI EFEKTYVUMO RODIKLIŲ REIKŠMĖS APRAŠOMOS INTERVALAIS

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S a n t r a u k a

Straipsnio tikslas – pasiūlyti alternatyvią daugelio rodiklių vertinimo metodiką. Šios metodikos išskirtinumas – rodiklių reikšmės, aprašomos intervalais. Tai labiau atitinka realias aplinkos sąlygas ir galimas reikšmes. Modelis su intervaluose pateiktomis efektyvumo rodiklių reikšmėmis pritaikytas E. K. Zavadsko ir A. Kaklausko sukurtam metodui COPRAS (Complex Proportional Evaluation). Taip gautas naujas metodas COPRAS-G. Šis metodas pritaikytas daugiabučių namų išorinių sienų efektyvumo vertinimo uždaviniui spręsti. Sudaryta efektyvumo rodiklių sistema, nustatyta efektyvumo rodiklių reikšmė, rodiklių rangas. Pagal sudarytą modelį pritaikę COPRAS-G metodą, galime spręsti daugelį statybos, vadybos alternatyvų vertinimo uždavinių.

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

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