10.2478/v10160-011-0005-z

Transactions of the VŠB – Technical University of Ostrava

No.1, 2011, Vol.XI, Civil Engineering Series

paper #5

Marcela HALÍŘOVÁ[1]

OPTIMIZING THE SELECTION OF MATERIALS FOR STRUCTURE SEPARATING WALLS IN BUILDINGS

OPTIMALIZACE VÝBĚRU SKLADBY MATERIÁLŮ PRO NENOSNÉ STĚNY VE STAVEBNÍCH OBJEKTECH

Abstract

Engineering structures are subject to many substantial requirements. The requirements relating to the construction elements and constructions are constructive technical, technological, economic, esthetical and all-societal. Today these enhanced requirements are translated into norms and laws and apply to all structures, even for non-bearing interior walls. The multi-criterion optimization method seem to be an effective tool a quick and responsible choice of a separating wall material. This method can be used as early as during the design and preparation of project documentation for construction.

Keywords

Building structure, separating wall, optimizing method.

Abstrakt

Na stavební konstrukce klademe mnoho závažných nároků, od stavebně technických, přes technologické, ekonomické, estetické až po celospolečenské. Tyto dnešní zpřísněné požadavky se promítají do norem a zákonů a platí pro všechny konstrukce, tedy i pro nenosné vnitřní příčky. Pro rychlý a zodpovědný výběr skladby příček se nabízí vícekriteriální optimalizační metoda, jako účinný nástroj, již při návrhu a přípravě projektové dokumentace stavby.

Klíčová slova

Stavební konstrukce, příčky, optimalizační metoda.

1 INTRODUCTION

In order to optimise the selection of non-bearing interior walls, the separating walls from traditional masonry materials [1] and gypsum board grid walls [2] were chosen.Plain separating walls from one prevailing material only were chosen to emphasise and highlight characteristic features of building materials used in these walls.

2 SELECTION OF FEASIBLE MATERIAL ALTERNATIVES

Only feasible material alternatives were chosen out of the set of available material alternatives. The material alternatives which are not used in this climate/territory have been excluded. Individual representatives with characteristic features were selected so that the assessment could be in line with reality.

[1] Ing. Marcela Halířová, Ph.D., Department of Building Constructions, Faculty of Civil Engineering, Technical University of Ostrava, Ludvíka Podéště 1875/17, 708 33 Ostrava - Poruba, phone: (+420) 597 321359, e-mail: marcela.halirova@vsb.cz.

10.2478/v10160-011-0005-z

Table 1: The selected feasible material alternatives for the internal non-bearing walls/partition walls

Code	Composition of the material alternative
A	Partition wall from full burnt bricks: plaster, MV, thickness 10mm / CP, 290x140x65 mm, thickness 140mm / plaster, MV, thickness 10 mm Total thickness of the partition wall: 160 mm
B	Partition wall from hollow brick slips, Supertherm CD 6 DF: plaster, MV, thickness 10 mm, / Supertherm CD 6 DF, 365x238x115mm, thickness 115 mm / plaster, MV, thickness 10 mm Total thickness of the partition wall: 135 mm
C	Partition wall from lime sand bricks: plaster, MV, thickness 10 mm / lime sand brick, 290x140x65, thickness 140 mm / plaster, MV, tl.10 mm Total thickness of the partition wall: 160 mm
D	Partition wall from shaped concrete bricks TP 12-B: plaster, MV, thickness 10 mm / TP 12-B, 500x190x120 mm, thickness 120 mm / plaster, MV, thickness 10 mm Total thickness of the partition wall: 140 mm
E	Partition wall from slip bricks Liapor M 115: plaster, MV, thickness 10 mm / Liapor M 115, 372x240x115 mm, thickness 115 mm / plaster, MV, thickness 10 mm Total thickness of the partition wall: 135 mm
F	Partition wall from slip bricks Ytong plaster, mortar Ytong, thickness 2,5 mm / NAP 10, 2100x599x100 mm, thickness 100 mm / plaster, mortar Ytong, thickness 2,5 mm Total thickness of the partition wall: 105 mm
G	Grate partition wall from gypsum board without loose thermal insulation GKB, thickness 12,5 mm / air gap, thickness 100 mm / GKB, thickness 12.5 mm Total thickness of the partition wall: 125 mm
H	Grate partition wall from gypsum board without thermal insulation GKB, thickness 12.5 mm / rock wool Orsil, tl.60 mm / air gap, thickness 40 mm / GKB, thickness 12.5 mm Total thickness of the partition wall: 125 mm

10.2478/v10160-011-0005-z

3 SELECTION OF THE DECISIVE PROPERTIES AND EVALUATION CRITERIA

An important step in the decision-making analysis is identification of decisive properties and partial optimising goals.

Table 2: Evaluation criteria selected for the multi-criteria optimising process

No.	Criterion	Unit
1	Surface weight	$kg.m^{-2}$
2	Heat transmission coefficient, U	$W.m^{-2}.K^{-1}$
3	Weighed laboratory air transmission loss, R_w	dB
4	Fire resistance, EI	min.
5	Price of sqm of partitition wall	$Kč.m^{-2}$
6	Work difficulty	-
7	Recycling rate	%

4 CREATION OF THE DECISION-MAKING MATRIX

In the optimising task within the multi-criterion process, there is an infinite number of elements in the set of material alternatives. These elements form the decision-making criterion matrix. In this matrix, the columns are the criteria, while the rows are the alternative assessments. See the equation (1).

Decision-making matrix:

$$\left|\begin{array}{cccc|c} a_{11} & a_{12} & \dots & a_{1n} & f_1 \\ a_{21} & a_{22} & \dots & a_{2n} & f_2 \\ . & . & \dots & . & . \\ . & . & \dots & . & . \\ . & . & \dots & . & . \\ a_{m1} & a_{m2} & \dots & a_{mn} & f_m \end{array}\right| \quad (1)$$

where: f_1 through f_m … the criterion weight, it holds good $\sum_{i=1}^{m} f_i = 1$

a_{ij} … the value of the *i* criterion and *j* alternative (where i=1 through m, j=1 through n).

The decision-making matrix comprises eight material alternatives marked with capital letters A through H (see Table 1) and seven assessment criteria marked with numbers (see Table 2). Each criterion is identified as max (maximising) or min (minimising), depending on the maximum or minimum being desirable and more suitable.

Table 3: Decision-making matrix:

Criterion No.	Max/min.	Material alternatives							
		A	B	C	D	E	F	G	H
1	max.	290	173	245	208	149	84	24,7	25
2	min.	2,81	2,41	2,81	2,46	1,82	1,31	2,20	0,60
3	max.	47	48	49	45	46	34	39	47
4	max.	180	150	120	90	120	60	15	45
5	min.	894	944	670	472	537	728	545	653
6	max.	1,667	1,667	1,833	3,167	3,167	4,333	5,0	5,0
7	max.	10	10	20	40	60	80	90	85

The values were calculated or taken from manufacturers' technical sheets. For details see the author's archives.

5 DETERMINING THE WEIGHT OF CRITERIA BY QUANTITATIVE MATCHING OF THE CRITERIA

The most important and crucial step in the multi-criterion optimising process is determination of the weight/relevance of each criterion. Every feature which is defined through the criteria has got a different relevance. The assessment of the relevance plays also an important role because an opinion of a user of the building might be different from priorities of the contractor or building material manufacturer. Most multi-criterion decision-making methods require accurate information about relative importance of individual criteria which can be expressed by means of criterion weight vectors.

$$v = (v_1, v_2, \ldots, v_k)\,,\ \sum_{i=1}^{k} v_i = 1\,,\ v_i \geq 0 \tag{2}$$

The higher is the criterion importance, the higher is the weight. The Saaty matrix can be used to express preference of individual criteria – the criteria can be heavily preferred, preferred or equal. Individual elements in the Saaty matrix are defined using the equation (3). The criterion weight is obtained from the equation (4).

Determination of the criteria relevance in an accountable way is an important creative phase of the multi-criterion optimising decision-making process.

$$s_{ij} \approx \frac{f_i}{f_j}\,;\ s_{ii} = 1\,;\ s_{ji} = \frac{1}{s_{ij}} \tag{3}$$

Below is the applicable verbal classification scale:

1 – equal criteria i and j;

3 – i is slightly preferred to j;

5 – i is strongly preferred to j;

7 - i is very strongly preferred to j;

9 – i is absolutely preferred to j.
The values – 2, 4, 6, 8 – are the intermediate levels of the verbal scale.

$$f_i = \frac{\left(\prod_{j=1}^{n} s_{ij}\right)^{\frac{1}{n}}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} s_{ij}\right)^{\frac{1}{n}}} \quad (4)$$

where:

-S = (s_{ij}) … is the matrix of Saaty matching where i, j = 1, 2, 3, …n
-f_i … the total weight of criteria

Table 4 Quantitative matching of the criteria

→j ↓i	2	3	4	5	6	9	1	S_{ij}	R_{ij}	f_i weight
2	1	1/3	1/3	1/5	1/5	1/3	3	0.00444	0.46	0.050
3	3	1	1/3	1/5	3	3	3	5.4	1.27	0.138
4	3	3	1	1/3	1	3	3	27	1.6	0.174
5	5	5	3	1	5	3	7	7875	3.6	0.393
6	5	1/3	1	1/5	1	1/3	3	0.333	0.85	0.093
9	3	1/3	1/3	1/3	3	1	5	1.666	1.07	0.117
11	1/3	1/3	1/3	1/7	1/3	1/5	1	0.00035	0.32	0.035
Σ									9.17	1

6 TRANSFORMING THE DECISION-MAKING MATRIX INTO A CALCULATION MATRIX FOR THE MULTI-CRITERION OPTIMISING PROCESS

The transformation is modification of criteria values for individual weights so that a sequence could be obtained. Then, the sequence of the alternatives is obtained and the values are converted into dimensionless numbers. This depends on the type of value of a specific criterion.

The criterion value is of a cost-type if the requirement is given by its minimum value. Such criteria include economic costs, energy consumption, work complexity, quantity of harmful emissions or a specific unit weight.

The transformation is carried out as follows: The maximum maxa_{ij} corresponds to the lowest assessment value (typically b_{ij} = 0) and the minimum value min a_{ij} corresponds to the highest assessment (b_{ij} = 1).

$$b_{ij} = \frac{(\max a_{ij}) - a_{ij}}{(\max a_{ij}) - (\min a_{ij})} \quad (5)$$

The criterion value is of a profit-type if the requirement is given by its maximum value. This means, the higher are the values of the criteria, the better is the assessment.

The dimensionless quantity is transformed as follows:

$$b_{ij} = \frac{(a_{ij}) - (\min a_{ij})}{(\max a_{ij}) - (\min a_{ij})} \tag{6}$$

The decision-making matrix is transformed into the calculation matrix using the formula (7).

Calculation matrix:

$$\left|\begin{array}{cccc|c} b_{11} & b_{12} & \dots & b_{1n} & f_1 \\ b_{21} & b_{22} & \dots & b_{2n} & f_2 \\ . & . & \dots & . & . \\ . & . & \dots & . & . \\ . & . & \dots & . & . \\ b_{m1} & b_{22} & \dots & b_{mn} & f_m \end{array}\right| \tag{7}$$

where:

$$b_{ij} \cdot f_i = c_{ij}; \max \sum_{j=1}^{n} c_{ij} = H_i \Rightarrow \text{optimum} \tag{8}$$

where: - b_{ij} ... is the transformed value according to (11) and (12)

- f_i ... the weight of the criterion

Transformation of a decision-making matrix into a calculation matrix results in the sequence of suitability of the material alternatives under assessment, A through H as well as the selection of the optimum alternative and alternative with the highest sum of products transformed into the criteria and weights. Because subjective assessment cannot be avoided, only major differences between the sums are taken into account. The material alternatives with the little difference in the sum are regarded as more or less equal.

Table 5 Calculation matrix

Criterion No.	Weight f_i	Material alternatives $c_{ij} = b_{ij} . f_{ij} . 100$							
		A	B	C	D	E	F	G	H
2	0.050	5.00	2.80	4.15	3.45	2.34	1.12	0	0.11
3	0.138	0	2.50	0	2.19	6.18	9.34	3.81	13.8
4	0.174	15.08	16.24	17.40	12.76	13.92	0	5.80	15.08
5	0.393	39.30	32.15	25.01	17.86	25.01	10.72	0	7.15
6	0.093	0.99	0	5.40	9.30	8.02	4.26	7.86	5.73
9	0.117	0	0	0.58	5.26	5.26	9.36	11.70	11.70
11	0.035	0	0	0.44	1.31	2.19	3.06	3.50	3.28
Σ	1	60.37	53.69	52.98	52.13	62.92	37.86	32.67	56.85

7 ASSESSMENT OF THE OPTIMUM ALTERNATIVES

The highest value of the sum of products of the transformed criterion weights in the calculation matrix is in the material alternative E. In this alternative, the partition wall is built from the Liaport slip bricks. The weights of the individual criteria are balanced. Even if the highest assessments are not reached individually, the E is the winner in the sum of the total assessments.

The second highest assessment was reached by the material alternative A. This is the partition wall made from full burnt bricks (according to Table 1). Having analysed the assessment of the individual properties of the partition wall carefully and in detail, the conclusion is that the material alternative E was given such a high score only thanks to good acoustics features and, in particular, thanks to the fire resistance, EI because the fire resistance is given a high weight. Other features and properties are not balanced – they are below average or even non-compliant. Because the weights of the individual criteria are rather unbalanced, this material alternative is classified within the least assessed group.

The next high assessment was given to the material alternative H. This is the grate partition wall made from gypsum boards with heat insulation (see Table 1). The features and properties of this partition wall are well balanced and above average. It is evident that the partition wall made from gypsum-based composites with heat insulation [2] has proved to be a very good solution among traditional building materials [1].

Other material alternatives with the balanced assessment include B, C and D. These are the partition walls made from hollow burnt brick slips (Supertherm), lime sand bricks and shaped brick slips from concrete (see Table 1).

The group with the lowest classification includes F and G. These are the partition wall made from Ytong brick slips and the grate partition wall from gypsum board without heat insulation.

8 CONCLUSION

The internal non-bearing walls/partition walls are an integral part of the structure in the building constructions. While the traditional materials have proved throughout centuries, it was only ČSN EN 520 [2] in May 2005.which introduced gypsum board materials into standardised assessment processes.

All criteria were chosen as necessary and most frequently required for the assessment of the material alternatives. All those criteria are not, however, valid for specific real walls and are not required simultaneously. In real buildings in practice, a situation should be avoided when any criterion were not required for the building at all. And such criterion would not be, logically, included into the assessment either. When dealing with specific tasks in the building practice, all these facts need to be taken into account.

Conclusions drawn when selecting the optimum alternative by means of the multi-criterion assessment can be used in the early stage of the preparation when the best material alternative should be chosen for the internal non-bearing walls.

The multi-criterion optimising process and quantitative matching of the criteria rank among fast and reliable methods used for the assessment of the building materials where subjective opinions of assessors are excluded and the procedure is clearly given for the assessment of the material alternatives.

For that reason, the assessment results are generally valid.

REFERENCES

[1] ČSN ENV 1996-1-1 *Navrhování zděných konstrukcí. Část 1-1: Obecná pravidla pro pozemní stavby. Pravidla pro vyztužené a nevyztužené zděné konstrukce*. Praha: Český normalizační institut, 1996. p. 168.

[2] ČSN EN 520 (72 3611) *Sádrokartonové desky – Definice, požadavky a zkušební metody.* Praha: Český normalizační institut, 2005. p. 44.

[3] FIALA, P., JABLONSKÝ, J., MAŇAS, M. *Vícekriteriální rozhodování*. Praha,VŠE Praha, 1996. p. 316. ISBN 80-7079-748-7

[4] Firemní materiály, technické podklady, atesty: Heluz cihlářský průmysl v.o.s., KM Beta a.s., Lias VINTÍŘOV Lehký stavební materiál k.s., Betonové stavby Klatovy s.r.o., Xella pórobeton CZ s.r.o., Rigips s.r.o., Knauf a.s., ROKWOOL a.s.

[5] HALÍŘOVÁ, M., SKULINOVÁ, D.: *Suchá výstavba*, Brno: ERA Group, spol. s r.o., 2007. p. 112. ISBN 80-7366-072-5

[6] PYTLÍK, P. *Vlastnosti a užití stavebních výrobků.* Brno, VUTIUM, 1998. p. 399. ISBN 80-214-1123-6

Reviewers:

Doc. Ing. Arch. Josef Šamánek, CSc.

Ing. Vladislav Varmuža, Kania, a.s.