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MULTI-CRITERION ANALYSIS OF BEAS – ENERGY PERFORMANCE INDICATORS

ANALIZA WIELOKRYTERIALNA BEAS – WSKAŹNIKI CHARAKTERYSTYKI ENERGETYCZNEJ

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A b s t r a c t

Building environmental assessment systems and tools used over the world were the base of new system development for Slovak conditions. The proposed fields are site selection and project planning; building construction; indoors environmental quality; energy performance; water and waste management. The fields and indicators were proposed on the bases of available information analysis from particular fields of building environmental assessment and also on the base of our experiments.

Keywords: building environmental assessment, multi-criteria analysis, system, method

S t r e s z c z e n i e

Środowiskowe systemy oceny budynków i narzędzia używane na całym świecie były podstawą opracowania nowego systemu dla obszarów na Słowacji. Proponowane obszary to: wybór lokalizacji i założenia projektowe, konstrukcja budynku, jakość środowiska wewnętrznego, wydajność energetyczna, woda i gospodarka odpadami. Cele i wskaźniki zostały zaproponowane na podstawy analizy dostępnych informacji z poszczególnych dziedzin oceny oceny oddziaływania budynku na środowisko, a także na podstawie naszych doświadczeń eksperymentalnych.

Słowa kluczowe: środowiskowe systemy oceny budynków, analiza wielokryterialna, system, metodologia

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1. Energy performance

Buildings today account for 40% of the world's primary energy consumption and are responsible for about one-third of global CO_2 emissions. Under the Kyoto Protocol, the European Union has committed itself to reducing the emission of greenhouse gases by 8% in 2012 compared with the 1990 level and buildings have to play a major role in achieving this goal. If building energy efficiency is improved by 22%, 45 million tonnes of CO_2 can be saved, nearly 14% of the agreed total savings of 330 million tonnes. The European Directive for Energy Performance of Buildings, signed by the European Parliament and Council in 2002, was created to unify the diverse national regulations and calculation methods, to define minimum common standards on building energy performance and to provide certification and inspection rules for a building and its heating and cooling plants. Although the performance directive only defines a common methodology for energy certification, most European countries have now increased their requirements to limit new buildings' energy demand [1].

Energy consumption in buildings can take place in two ways: energy capital that goes into production and transportation of building materials and assembling of the building (embodied energy), and energy for the maintenance/servicing of a building during its useful life. The second one greatly depends on the climatic variations in a particular region. The first one is a one-time investment, which can vary over wide limits depending upon choice of building materials and techniques [2].

The technological and social dynamics that determine energy demand are of central importance to managing energy systems. Total demand for primary energy resources depends on both the efficiency of the processes used to convert primary energy to useful energy and the intensity with which useful energy is used to deliver services. For example, total demand for a primary resource like coal depends not only on the efficiency with which coal is converted to electricity, but also on the intensity with which electricity is used to deliver services such as lighting or refrigeration [3].

Therefore, energy performance is main field in building environmental assessment.

2. Building environmental assessment

Building environmental assessment is a specific complex of proceedings oriented to systematic and objective evaluation of building performance. These processes lead to design, construction and operation of buildings with respect to criteria of sustainable development. Building environmental assessment is not only tool of control, but also tool of sustainable building design. The development of building environmental assessment is enhanced for last nineteen years over the world. The number of building environmental assessment systems/methods has increased from the introduction of BREEAM (UK). The other significant systems developed in many countries are Green Globes (Canada), LEED (USA), SBTool (international), NABERS (Australian), CASBEE (Japan), HK-BEAM (Hong Kong), France HQE (France), E-audit (Poland), Protocollo ITACA (Italy), LEnSE (EU). The assessment systems are based on the building's life cycle: pre-design, new buildings, existing buildings, and renovation. In previous time the requirements on environmental safety, suitability and responsibility of buildings have been increased. The criteria of sustainability are included in building environmental assessment systems used in different countries for evaluating the sustainable and environmental performance.

2.1. Building environmental assessment system in Slovakia

The building environmental assessment system (BEAS) has been developed in Slovakia as well through the last years. This topic is very discussed between architects, designers and developers in Slovakia. The main fields and determining indicators of BEAS are proposed on the base of available information analysis from particular fields and also on the base of our experimental experiences. The proposed indicators respect Slovak standards and rules. The background of BEAS development was mainly SBTool [1–4].

In this table (Table 1) is shown hierarchy structure of proposed building environmental assessment system. The proposed main fields in BEAS are site selection and project planning; building construction; indoor environmental quality; energy performance; water and waste management. System has six main fields: A – Site Selection and Project Planning, B – Building Construction, C – Indoor Environment, D – Energy Performance, E – Water Management, F – Waste Management. Some of main fields have subfields, for example field marked as A has two subfields A1 – Site selection and A2 – Site development. Fields and subfields have indicators of assessment. System BEAS has total 52 indicators of assessment.

In the table (Table 2) is shown main field D – Energy performance with weight determined by Saaty's method. This field has three subfields: D1 – Operation Energy, D2 – Active systems using renewable energy sources and D3 – Energy management. These subfields have several indicators of assessment.

Hierarchy structure allowed using Multicriteria analysis (MCA) for weight significance determination. MCA is a tool for effectiveness evaluation and decision support. One of the Multicriteria analysis methods is Analytic hierarchy process (AHP). AHP is a theory of measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales. It is these scales that measure intangibles in relative terms. The comparisons are made using a scale of absolute judgments that represents how much more; one element dominates another with respect to a given attribute [5–7].

Table 1

Hierarchy structure

BEAS									
A		**B**		**C**	**D**			**E**	**F**
A1	A2	B1	B2	C1	D1	D2	D3	E1	F1
A1.1	A2.1	B2.1	B2.1	C2	D1.1	D2.1	D3.1	E2	F2
A1.2	A2.2	B2.2	B2.2	C3	D1.2	D2.2	D3.2	E3	F3
A1.3	A2.3	B2.3	B2.3	C4	D1.3	D2.3		E4	
A1.4	A2.4	B2.4		C5	D1.4				
A1.5	A2.5	B2.5		C6	D1.5				
A1.6	A2.6			C7					
A1.7	A2.7			C8					
A1.8				C9					
A1.9				C10					
A1.10									

Table 2

Energy performance in system BEAS

Main field	Weight [%]	Subfieds	Weight [%]	Indicators	Weight [%]*	Weight [%]**
D Energy performance	26,45	D1 Operation Energy	56,25	D1.1 Energy needs for heating	23,08	3,43
				D1.2 Energy needs for domestic hot water	23,08	3,43
				D1.3 Energy needs for mechanic ventilation and cooling	23,08	3,43
				D1.4 Energy needs for lighting	17,95	2,67
				D1.5 Energy needs for appliances	12,82	1,91
		D2 Active systems using renewable energy sources	25	D2.1 Active solar design	36	2,38
				D2.2 Heat pump	32	2,12
				D2.3 Photovoltaic technology and heat recuperation	32	2,12
		D3 Energy management	18,75	D3.1 System of energy management	50	2,48
				D3.2 Operation and maintenance	50	2,48

2.2. Methods used

Mathematical mechanism for evaluation processes in the field of environmental engineering is extensive. There are many methods for the determination of criteria significance, parameters significance, control of dependency, tests of sensitivity etc. Objective methods was analyzed and evaluated in context of building environmental assessment requirements in benefit with respect to qualitative and quantitative characteristic of ranking the significance of the particular indicators. Following analyze of criteria weights estimation methods were determined by Saaty's method. This method was used for determination percentage weight of fields and indicators of assessment. The Saaty's method enables us to model a complicated decision problem with the help of a hierarchical structure that is composed of the goal, criteria, sub criteria and alternatives. The advantage of this method is the possibility to handle both qualitative, as well as quantitative objects.

2.2.1. Saaty's method

The Saaty's method enables us to model a complicated decision problem with the help of a hierarchical structure that is composed of the goal, criteria, sub criteria and alternatives. The advantage of this method is the possibility to handle both qualitative, as well as quantitative objects. The output of this method is a mathematically correct quantitative evaluation of alternatives being assessed. The Saaty's method dealt with consistency of the pairwise comparison matrix. A consistent matrix mean e.g. if the decision maker says a criterion i is as important as another criterion j (so the comparison matrix will contain value of a_{ij} = 1= a_{ji}), and the criterion j is absolutely more important as the criterion *i* (a_{ji} = 9; a_{ij} = 1/9); then the criterion *i* should also be absolutely more important than the criterion *j* (a_{ij} = 9; a_{ji} = 1/9). The idea is based on the fact that it is easier for a person to come up with relational evaluations rather than with absolute evaluations. In addition, comparing items in pairs renders the most accurate evaluation of an assessed characteristic; the Saaty scale is used for that. In the table (Table 3) is scale of relative importance for pairwise comparison. This scale consists from intensity of importance and descriptor. A nine point scale is provided to quantify pairwise importance or preference and intermediate values are used to interpolate between adjacent scale values. After conducting such comparisons, what follow is the derivation of different alternatives' weights, as well as that of the criteria. This means composing absolute scales by using mathematical methods described by Saaty. It is an important fact that in conducting measurements, no standard scale has to be used – experience, intuition or knowledge is usually sufficient [8–10].

Table 3

Scale of relative importance for pairwise comparison

Intensity of Importance	Descriptor	
	Verbal Scale	Explanation
1	Equal importance of both elements	Two elements contribute equally
3	Moderate importance of one element over another	Experience and judgment favor one element over another
5	Strong importance of one element over another	An element is strongly favored
7	Very strong importance of one element over another	An element is very strongly dominant
9	Extreme importance of one element over another	An element is favored by at least an order of magnitude
Intensity of 2, 4, 6, and 8 can be used to express intermediate values. Intensities 1.1, 1.2, 1.3, etc. can be used for elements than are very close in importance.		

In the table below (Table 4) is presented the example of main field – D – Energy performance weighting by Saaty. The criteria weight was assigned using Saaty's matrix.

Table 4

Example of Analytic hierarchy process (Saaty) method – D – Energy performance

$a(i, j)$	Criteria			$\Pi\ a(i, j)$	$R(i) = [\Pi\ a(i, j)]^{1/3}$	Weights $v(i)$	%
Criteria	D1	D2	D3				
D1	1,00	5,50	2,00	11	2,224	0,692	69,2
D2	0,18	1,00	1,00	0,181818	0,567	0,176	17,6
D3	0,15	0,50	1,00	0,076923	0,425	0,132	13,2
Total:					3,780	1,000	100

In the next table (Table 5) is presented the example of weighting of indicators in first subfield D1 – Operation energy. The criteria weight was assigned using Saaty's matrix.

Table 5

Example of Analytic hierarchy process (Saaty) method – D1 – Operation energy

$a(i, j)$	Criteria					$\Pi\ a(i, j)$	$R(i) = [\Pi\ a(i, j)]^{1/5}$	Weights $v(i)$	%
Criteria	D1.1	D1.2	D1.3	D1.4	D1.5				
D1.1	1,00	2,00	3,50	5,00	5,00	175	2,809	0,438	43,8
D1.2	0,50	1,00	3,50	4,00	4,00	28	1,947	0,304	30,4
D1.3	0,29	0,29	1,00	2,00	2,00	0,163265	0,696	0,109	10,9
D1.4	0,20	0,25	0,50	1,00	1,00	0,025	0,478	0,075	7,5
D1.5	0,20	0,25	0,50	1,00	1,00	0,025	0,478	0,075	7,5
Total:							5,801	1,000	100

In the next table (Table 6) is presented the example of weighting of indicators in second subfield D2 – Active systems using renewable energy sources. The criteria weight was assigned using Saaty's matrix.

Table 6

Example of Analytic hierarchy process (Saaty) method – D2 – Active systems using renewable energy sources

$a(i, j)$	Criteria				$\Pi\ a(i, j)$	$R(i) = [\Pi\ a(i, j)]^{1/4}$	Weights $v(i)$	%
Criteria	D2.1	D2.2	D2.3	D2.4				
D2.1	1,00	3,50	3,00	5,00	52,5	2,692	0,535	53,5
D2.2	0,29	1,00	0,67	2,50	0,476190476	0,831	0,165	16,5
D2.3	0,33	1,50	1,00	3,00	1,5	1,107	0,220	22
D2.4	0,20	0,40	0,33	1,00	0,026666667	0,404	0,080	8
Total:						5,033	1,000	100

In the table below (Table 7) is shown the example of weighting of indicators in second subfield D3 – Energy management. The criteria weight was assigned using Saaty's matrix.

Table 7

Example of Analytic hierarchy process (Saaty) method – D3 – Energy management

$a(i, j)$	Criteria		$\Pi\ a(i, j)$	$R(i) = [\Pi\ a(i, j)]^{1/2}$	Weights $v(i)$	%
Criteria	D3.1	D3.2				
D3.1	1,00	1,00	1	1,000	0,500	50
D3.2	1,00	1,00	1	1,000	0,500	50
Total:				2,000	1,000	100

2.2.2. Pairwise comparison method – Fuller method

It is need to consider the assessment of the alternatives under the respective criteria. In the base pairwise comparisons step of the AHP, two alternatives a_i and a_j are presented to the decision maker where after he/she it is requested to judge them under a particular criterion. The underlying assumptions are: a) under the given criterion the two alternatives have subjective values a_i and a_j for the decision maker, and b) the judgmental statement whereby he/she expresses his/her relative preference for a_i with respect to a_j provides an estimate of the ratio a_i/a_j [11].

Pairwise preference ratios are presented in the cells of a table. Weights can also be normalized (put on 0 to 1 scale). Consistency checks between weightings are possible and necessary.

2.2.3. Final weights

In table (Table 8) is shown main fields and four weighting system variant. Three variant (V1, V2, V3) has been determined by Saaty method and one variant (V4) has been determined by Fuller method.

Determined weights of significance was analyzed and compared with weights of significance determined in various systems used over the world. On the base of comparison and consistently analysis of four variants it is most suitable third variant determined by Saaty method [6].

Table 8

Main fields and weighting variants

Main fields		Saaty method weights [%]			Fuller method weights [%]
		V1	V2	V3	V4
A	Site Selection and Project Plannig	14,15	19,54	14,71	13,46
B	Building Construction	12,36	17,45	20,59	19,87
C	Indoor Environment	19,45	21	23,56	26,28
D	**Energy Performance**	**27,99**	**23,63**	**26,47**	**32,69**
E	Water Management	11,91	10,5	8,88	7,05
F	Waste Management	14,15	7,88	5,88	0,64

3. Conclusions

The approaches of the assessment methods used in many countries are principally not different. The proposed environmental assessment system of buildings applicable in Slovak conditions consists of 6 main fields and 52 relevant indicators. The main fields are building site and project planning, building constructions, indoor environment, energy performance, water management and waste management. The weight significant of indicators/issue in used systems in field of building energy performance follows the national conditions and requirements. In this paper is presented indicators related to energy performance and also the way of determination of weight significance of energy field in BEAS. The weight of energy performance is 26,47%. It is the most percentage weight significance from all main fields. This field consists of 3 subfields and 11 indicators. The first subfield D1 – Operation

Energy has weight 56,25%, the second subfields D2 – Active systems using renewable energy sources has weight 25% and the third subfields D3 – Energy management has weight 18,75%.

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