BUILDING ENVIRONMENTAL ASSESSMENT SYSTEM - WEIGHT DETERMINATION

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Summary

In Slovakia the building environmental assessment system is developed. The existing systems and tools were the base of development for new system available in Slovak conditions. The fields and indicators of building environmental assessment were proposed on the bases of available information analysis from particular fields of building environmental assessment and also on the base of our experimental experiences. The proposed main fields are site selection and project planning; building construction; indoor environment; energy performance; water and waste management. Percentage weight of fields and indicators was determined on the base of their significance, according to mathematical method. 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 the context of building environmental assessment requirements in benefit with respect to qualitative and quantitative characteristic of ranking the significance of the particular indicators. The following analyze of criteria weights estimation methods were determined by Saaty's method. This method was used for determination percentage weight of the fields and indicators. This paper deals with the significance weight determination of building environmental assessment fields and indicators.

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

1 Building environmental assessment

The increase in public awareness about the depletion of the quality of the environment has led us to a plethora of policies for protecting the environment, especially the impact of buildings on the environment [1]. Sustainable building design, construction and operation require innovations in both engineering and movement areas at all stages of a building's life [2]. Sustainable building has three dimensions: ecological, cultural, and economic sustainability. The assessment of a sustainable building has to make explicit the particular

cultural expectation witch the development has been designed to maintain [3]. Since some decade ago, there has been a concern for resource depletion and environmental pollution associated with properties and surrounding infrastructures. In addressing such impact of the built environment, there is recognition of the existence of alternative building materials, fuels for energy supply, source, source for water supply and options for wastewater treatment as well as technologies for waste handling and disposal [4]. 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 (Australia), CASBEE (Japan), HK-BEAM (Hong Kong), LEnSE (EU), France HQE (France), E-audit (Poland), Protocollo ITACA (Italy). In the table (**Tab. 1**) is most significant building environmental assessment systems used over the world.

Tab. 1 The most significant building environmental assessment systems used over the world

System	Country	Initiated	Main fields	Result
BREEAM	UK	1990	Management, Healthy and well being, Energy use, Pollution transport, Materials, Land&ecology, Waste Water	Pass, Good, Very Good, Excellent
Green Globes	Canada	2004	Energy, Water, Resources, Indoor environment, Emissions, Environmental management	One to four globes (1=35-54%, 2=55-69%, 3=70-84%, 4=+85%)
SBTool	28 countries	1996	Site selection, Project planning and development; Energy and resource consumption; Environmental loadings; Indoor environmental quality; Functionality and controllability of building systems; Long-term performance; Social & economic aspects	Range of detailed and broad Histograms
LEED	USA	1998	Sustainable site, Water efficiency, Energy & Atmosphere, Materials & Resources, Indoor environmental quality, Innovation & Design process	Certified (40%), Silver (50%), Gold (60%), Platinum (80%)
CASBEE	Japan	2001	Quality Q – Building environmental quality and performance; Loadings L – Reduction of building env. loadings	"spider web" diagram, histogram
HK-BEAM	Hong Kong	1996	Site aspects, Materials aspect, Water use, Energy use, Indoor environmental quality, Innovations and performance enhancements	Bronze (40 %) Silver (55 %) Gold (65 %) Platinum (75 %)
NABERS	Australia	2001	Land, Materials, Energy, Water, Interior, Resources, Transport, Waste	Green, Bronze, Silver, Gold, Platinum
LEnSE	**	2006	Environmental aspects, Social aspects, Economical aspects	LEnSE output

**Belgium, France, GB, Germany, Netherlands, Greece, Switzerland, Czech Republic

1.1 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 [5, 6, 7, 8].

1.1.1 Main fields

In this table (**Tab. 2**) 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 determining indicators. The total number of the indicators is 52.

Tab. 2 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									

Hierarchy structure allowed using Multi-criteria analysis (MCA) for weight significance determination. MCA is a tool for effectiveness evaluation and decision support. One of the Multi-criteria 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 [9, 10, 11]. The multi-criteria framework incorporates the consideration of environmental issues in a development and it will take an important role in the evaluation approach [4].

2 Method

The developed building environmental assessment system (BEAS) for Slovakia contains six main fields and 52 indicators. Significance weight of proposed fields and indicators

were determined by mathematical method. Mathematical mechanism for evaluation processes in field of environmental engineering is extensive. There are many methods for determination of significance criteria, significance parameters, control of dependency, tests of sensitivity etc. For example: Multi-criteria analysis, Analytic hierarchy process, Saaty's method, Metfessel allocation, Point method, Pairwise comparison method - Fuller method, etc. These methods were analyzed and evaluated in the context of environmental assessment requirements in benefit with respect to qualitative and quantitative characteristic of determining indicators ranking. Consequent analysis of methods for criteria weights estimation was performed. The Saaty's method was used for determination of indicators percentage weight.

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 (**Tab. 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 [10, 11, 12].

Tab. 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 (**Tab. 4**) is presented the example of main field's weighting by Saaty's method. The criteria weight was assigned using Saaty's matrix. The main fields are marked: A – Site Selection and Project Planning, B – Building Construction, C – Indoor Environment, D – Energy Performance, E – Water Management, F – Waste Management.

Tab. 4 Example of Analytic hierarchy process (Saaty) method (Variant 1)

a(i,j)	Criteria						Π	R(i) =	Weights	%
Criteria	A	B	C	D	E	F	$a_{(i,j)}$	$[\Pi\, a(i,j)]^{1/6}$	v(i)	
A	1,00	1,00	0,67	0,50	1,50	1,00	0,5	0,891	0,141	14,15
B	1,00	1,00	0,67	0,50	0,67	1,00	0,22	0,778	0,124	12,36
C	1,50	1,50	1,00	0,67	1,50	1,50	3,37	1,225	0,194	19,45
D	2,00	2,00	1,50	1,00	2,50	2,00	30	1,763	0,280	27,99
E	0,67	1,50	0,67	0,40	1,00	0,67	0,17	0,750	0,119	11,91
F	1,00	1,00	0,67	0,50	1,50	1,00	0,5	0,891	0,141	14,15
Total:								6,297	1,000	100

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 ai with respect to a_j provides an estimate of the ratio a_i/a_j [9]. 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.

2.3 Final weights

In table (**Tab. 4**) 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 (**Tab. 5, Fig. 1**). On the base of comparison and consistently analysis of four variants it is most suitable third variant determined by Saaty method.

Tab. 5 Main fields and weighting variants

Main fields		Saaty method weights [%]			Fuller method [%] - V4
		V1	V2	V3	
A	Site Selection and Project Planning	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

Tab. 6 Percentage weightings of building environmental assessment main fields

Main fields	**BEAS [%]**	**SBTool [%]**	**Green Globes [%]**	**LEED [%]**	**CASBEE [%]**	**HK-BEAM [%]**	**NABERS [%]**
Site Selection and Project Planning	14,71	12,5	11,5	20	15	13,2	16,67
Building Construction	20,59	0	10	19	13	12,3	13,33
Indoor Environment	23,53	16,7	20	22	20	25,9	6,67
Energy Performance	26,45	20,8	36	25	20	41,3	16,67
Water Management	8,82	0	10	7	2	6,3	6,67
Waste Management	5,88	22	12,5	0	0	0	0
Others	0	28	0	7	30	1	40

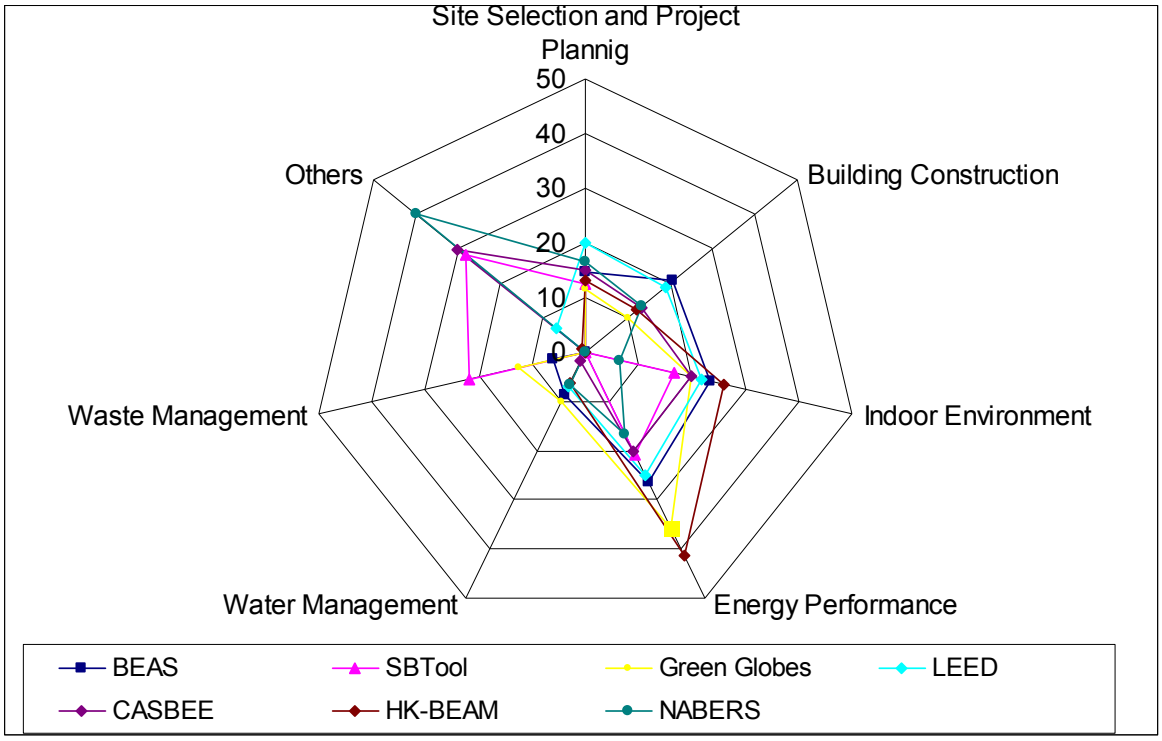


Fig. 1 Percentage weightings of building environmental assessment main fields

In the figure (**Fig. 2**) is shown final percentage weighting of main fields in BEAS.

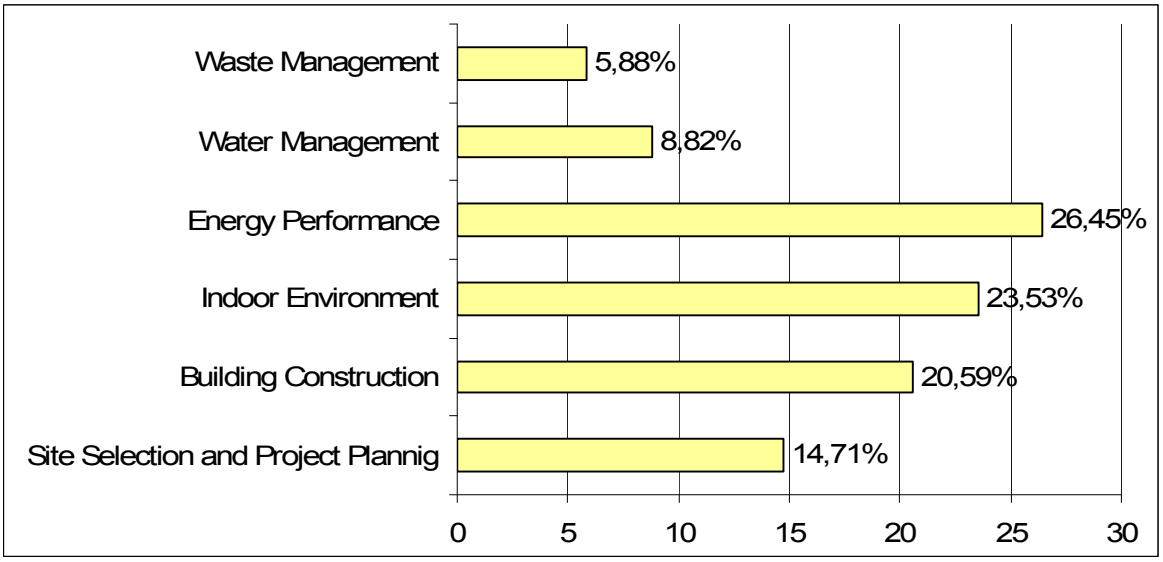


Fig. 2 Final percentage weightings in BEAS

3 Software tool for building environmental assessment system

As a support of BEAS was developed software tool which allows easy and comprehensive evaluation of buildings. The software tool for BEAS is on the base of international software tool in Microsoft Excel for building environmental assessment – SBTool.

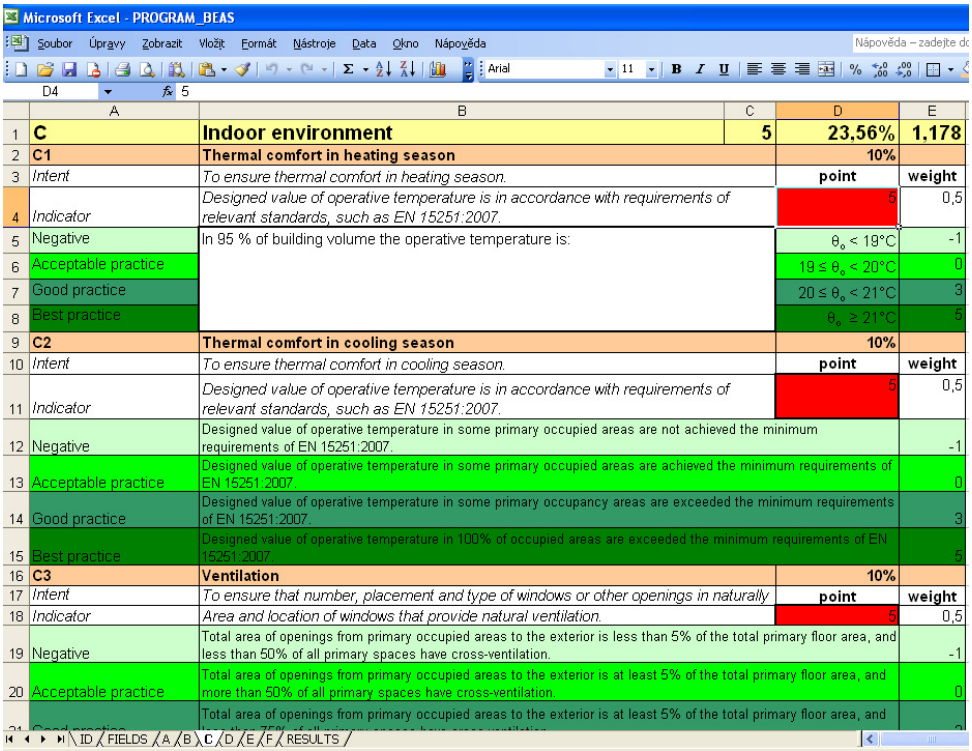
Program has nine evaluative lists. First evaluative list serves the identification of assessed building. The register of main fields and determining indicators is in second evaluative list. The field marked:

- A – Site selection and project planning is assessed in third evaluative list,
- B – Building construction is assessed in fourth evaluation list,
- C – Indoor environment is assessed in fifth evaluative list,
- D – Energy performance is assessed in sixth evaluative list,
- D – Water management is assessed in seventh evaluative list and
- F – Waste management in eighth evaluative list.

In the last evaluative list there are transferred results in the table and to the column graph. A manual was proposed as an aid to building environmental assessment tool.

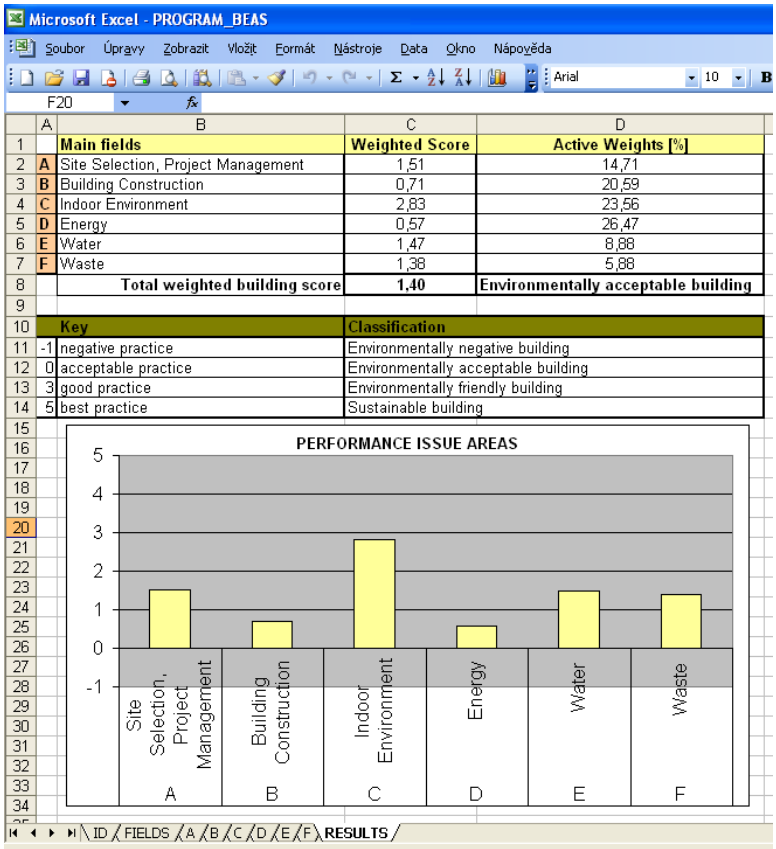
In the figure (**Fig. 3**) is shown third assessed field marked C – Indoor environment. The way of indicators evaluation is in principle the same. All performance criteria are evaluated according to standards and laws valid in Slovak Republic. Each main field has several indicators of assessment which have the intent of assessment and the scale of assessment. This scale is from negative (-1 point), acceptable practice (0 point), good practice (3 point) and best practice (5 point).

Result of each indicator assessment is obtained so that the point from scale is multiplying with weight of indicator. This result is presented in last evaluative list in form of column graph and comprehensive tables. In the figure (**Fig. 4**) is shown the last evaluative list marked as results [14, 15].



	A	B	C	D	E
1	**C**	**Indoor environment**	**5**	**23,56%**	**1,178**
2	**C1**	**Thermal comfort in heating season**		**10%**	
3	*Intent*	*To ensure thermal comfort in heating season.*		**point**	**weight**
4	*Indicator*	*Designed value of operative temperature is in accordance with requirements of relevant standards, such as EN 15251:2007.*		5	0,5
5	Negative	In 95 % of building volume the operative temperature is:		$\theta_o < 19°C$	-1
6	Acceptable practice			$19 \leq \theta_o < 20°C$	0
7	Good practice			$20 \leq \theta_o < 21°C$	3
8	Best practice			$\theta_o \geq 21°C$	5
9	**C2**	**Thermal comfort in cooling season**		**10%**	
10	*Intent*	*To ensure thermal comfort in cooling season.*		**point**	**weight**
11	*Indicator*	*Designed value of operative temperature is in accordance with requirements of relevant standards, such as EN 15251:2007.*		5	0,5
12	Negative	Designed value of operative temperature in some primary occupied areas are not achieved the minimum requirements of EN 15251:2007.			-1
13	Acceptable practice	Designed value of operative temperature in some primary occupied areas are achieved the minimum requirements of EN 15251:2007.			0
14	Good practice	Designed value of operative temperature in some primary occupancy areas are exceeded the minimum requirements of EN 15251:2007.			3
15	Best practice	Designed value of operative temperature in 100% of occupied areas are exceeded the minimum requirements of EN 15251:2007.			5
16	**C3**	**Ventilation**		**10%**	
17	*Intent*	*To ensure that number, placement and type of windows or other openings in naturally*		**point**	**weight**
18	*Indicator*	*Area and location of windows that provide natural ventilation.*		5	0,5
19	Negative	Total area of openings from primary occupied areas to the exterior is less than 5% of the total primary floor area, and less than 50% of all primary spaces have cross-ventilation.			-1
20	Acceptable practice	Total area of openings from primary occupied areas to the exterior is at least 5% of the total primary floor area, and more than 50% of all primary spaces have cross-ventilation.			0
		Total area of openings from primary occupied areas to the exterior is at least 5% of the total primary floor area, and			

Fig. 3 Example of assessment – main field marked C – Indoor environment



	A	B	C	D
1		**Main fields**	**Weighted Score**	**Active Weights [%]**
2	A	Site Selection, Project Management	1,51	14,71
3	B	Building Construction	0,71	20,59
4	C	Indoor Environment	2,83	23,56
5	D	Energy	0,57	26,47
6	E	Water	1,47	8,88
7	F	Waste	1,38	5,88
8		**Total weighted building score**	**1,40**	**Environmentally acceptable building**
9				
10		**Key**	**Classification**	
11	-1	negative practice	Environmentally negative building	
12	0	acceptable practice	Environmentally acceptable building	
13	3	good practice	Environmentally friendly building	
14	5	best practice	Sustainable building	

Fig. 4 Example of results

4 Conclusions

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 weighting coefficients were developed to suit local conditions such as climate or to reflect the prioritized policies and will be modified for various type of buildings. The theoretical level of present knowledge of building environmental assessment is completely. It is necessary to implement this knowledge to construction practice. For the purpose of assessment system verification, it is needed to evaluate a statistically significant set of buildings. The results from further system verification will allow modify the significant weights of indicators.

Acknowledgement

The authors are grateful to the Grant Agency of Slovak Republic to support of project No. 1/0188/10, on the base of which the results are presented.

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