Building Environmental Assessment of Construction and Building Materials

Eva Krídlová Burdová[1], Silvia Vilčeková[2]

Institute of Environmental Engineering, Faculty of Civil Engineering, Vysokoškolská 4, 042 00, Košice, Slovakia

[1]eva.kridlova.burdova@tuke.sk; [2]silvia.vilcekova@tuke.sk

***Abstract*- Sustainability assessment of buildings can be defined as a specific complex of proceedings oriented towards systematic and objective evaluation of a building's performance. These processes lead to the design, construction and operation of buildings with respect to criteria for sustainable development. Since previous instances, the requirements of environmental safety, suitability and responsibility of buildings have increased. The criteria of sustainability are included in building environmental assessment systems and tools used in different countries for evaluating their sustainable and environmental performance. In recent years the evaluation of building performance in terms of environmental, social and economic aspects has become a topic of discussion in the Slovak Republic, as well. The purpose of this paper is to introduce the building environmental assessment system (BEAS), which was developed at the Technical University of Košice. The Slovak system was developed on the basis of existing systems used in many countries. The BEAS covers number of environmental, social and cultural factors. The manner and form of indicators evaluation is proposed according to the SBTool. The proposal of the main fields results from the quality of the outdoor and indoor environment, nature and landscape conservation, exploitation of natural resources and so on. The indicators were proposed according to available information analysis from particular fields of building performance as well as on the base of own experimental experiences. The field of building construction will be introduced in the paper.**

Keywords*- *Sustainable Buildings; Environmental Assessement Of Buildings; Building Construction

I. INTRODUCTION

In the past decade, building environmental assessment systems, methods and tools have been developed and used in different countries for evaluating the sustainable and environmental performance of buildings. Building environmental assessment is a specific complex of proceedings oriented towards systematic and objective evaluation of a building's performance. These processes lead to the design, construction and operation of buildings with respect to criteria for sustainable development. The building environmental assessment is not only a tool for control, but also a tool of sustainable building design. The purposes of building assessments from environmental aspects are due to the determination of real building states from a safety and reliability point of view, the possibility of building comparisons, the effect of environmental buildings potential and the proposal of measures resulting in sustainable buildings.

Although sustainable building is a multidimensional concept, attention to the issue often focuses solely on environmental indicators, ignoring the substantial importance of social, economic and cultural indicators. Building sustainability involves various relations between built, natural and social systems and therefore comprises a complex of different priorities that require consideration at each stage of a building's life-cycle. To cope with this complexity and to support sustainability systematic, holistic and practical approaches to building design need to be developed. The main objective of a systematic methodology is to support the development of a building design that achieves the most appropriate balance between the different sustainability dimensions, and is, at the same time, practical, transparent and flexible enough to be easily adapted to different types of buildings and technology [1].

II. REVIEW OF LITERATURE

The purpose of sustainability assessments is to gather and report information for decision-making during the different phases of construction, design and use of a building. The sustainability scores or profiles based on indicators result from a process in which the relevant phenomena are identified, analysed and valued. At present, it is possible to identify two opposite trends at work in the process: on one hand, the indicators commonly used by the different operators are characterised by their complexity and diversity while; on the other hand, there is a growing movement towards better usability through common understanding and simplicity. Building sustainability assessments based on a life-cycle approach can produce important long-term benefits for both building owners and occupants [2], namely: helping to minimize environmental impacts; solving existing building problems; creating healthier, more comfortable and more productive indoor spaces, and reducing building operation and maintenance costs. Life-cycle analysis considers all the inputs and outputs of acquiring, owning, and disposing of a building system. This approach is particularly useful when project alternatives, which fulfil the same performance requirements, but differ with respect to initial costs and operating costs, have to be compared in order to select the one that maximizes net savings [1, 2]. The development of assessment methods and the respective tools is a challenge both for the academia and in practice. An issue of prime importance is that of managing the flows of information and knowledge between the various levels of indicator systems. An important constraint to these methods is that the specific definition of the terms "sustainable building" or "high performance building" is complex, since different actors in the building's life-cycle have different interests and requirements [3]. For instance, promoters will give more attention to economic issues, whereas the end users are more interested in health and comfort issues [1]. In assessing the performance of buildings, the scope of environmental evaluation is widening, marking an evolution from a single criterion consideration, like the economic performance of buildings, towards a full integration of all aspects emerging during the lifetime of a building and its elements. It becomes therefore clear, that "Sustainable Buildings" is a broad, multi-criteria subject related to three basic interlinked parameters: economics, environmental issues, and social parameters [4]. Also, modern buildings and their Heating, Ventilating, and Air Conditioning systems (HVAC) are nowadays required not only to be more energy efficient while adhering to an ever-increasing demand for better performance in terms of comfort, but equally in respect to financial and environmental issues [5, 6, 7]. Building energy consumption comprises approximately 40% of an industrial nation's total energy consumption [8] leading to the respective emissions. A recent EU directive defines ambitious goals for reducing energy consumption and greenhouse gas emissions and requires all buildings constructed in 2020 or later to be "nearly zero-energy buildings" [9]. This calls for performance-oriented building design, aiming to develop design configurations that have low resource consumption and emissions and that are economically feasible. To achieve significant improvement, one key is using the appropriate building modelling methods, considering the relevant engineering interdependencies, especially in early phases, to support the design process and the involved design experts. Sustainable building design requires considering the geometric and visual properties of the design as well as the physical, technical, and economic engineering interdependencies that determine the building's performance [10]. Almost all environmental assessment methods have been designed to suit a specific territory.

Evidence [3, 11, 12, 13, 14] suggests that existing environmental assessment methods were developed for different local purposes, and are not fully applicable to all regions. More specifically, certain environmental factors may hinder the direct use of any existing environmental assessment. Examples of such factors are as follows: Climatic conditions; Geographical characteristics; Potential for renewable energy gain; Resource consumption (such as water and energy); Construction materials and techniques used; Building stocks; Government policy and regulation; Appreciation of historic value; Population growth; Public awareness [11]. Many methodologies have been developed to establish the degree of accomplishment of environmental goals, guiding the planning and design processes. In these earlier stages of the construction process, planners can make decisions to improve building performance at very little or no cost, following the recommendations of the decision-making tool. The development of building environmental assessment is enhanced for last twenty years over the world. The first of such tools was in 1990 the Building Research Establishment Environmental Assessment Method (BREEAM) [15]. After that, other methodologies, such as the Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) from Japan [16], the Building and Environmental Performance Assessment Criteria (BEPAC) from Canada [17], the Building Environmental Assessment Method (BEAM) from Hong Kong [18], the Green Building Rating System (SABA) from Jordan [2], Estidama from Emirate [19] and the Leadership in Energy and Environmental Design (LEED) from the United States [20] were developed and are currently widely applied. Very comprehensive inventories of available tools for environmental assessment methods can be found in Ding [21], in Seo [22], the Whole Building Design Guide [23], and the World Green Building Council [24, 25, 26]. There are a growing number of environmental assessment systems and tools being developed for the building sector. The most significant building environmental assessment systems used worldwide and main field of assessment and year of initiated is shown in Table 1.

TABLE I WORLDWIDE SYSTEM

System	Country	Initiated	Main fields
BREEAM	UK	1990	Management Health & Wellbeing Energy Transport Water Materials Waste Land Use & Ecology Pollution
Green Globes	Canada	2004	Project Management Site Energy Water Resources Emissions, Effluents & Other Impacts Indoor Environment
LEED	USA	1998	Sustainable Sites Water Efficiency Energy and Atmosphere Indoor Environmental Quality Innovation in Design Regional Priority
SBTool	28 counties	1996	Site Selection, Project Planning and Development Energy and Resource Consumption Environmental Loadings Indoor Environmental Quality Service Quality Social and Economic aspects Cultural and Perceptual Aspects
NABERS	Australia	2001	Energy use and greenhouse emissions Water use Waste Indoor environment
BEAM	Hong Kong	1996	Site Aspect Material aspects Energy use Water Use Indoor Environmental Quality Innovations and additions
CASBEE	Japan	2001	Indoor environment Quality of services Outdoor environment on site Energy Resources and materials Reuse and reusability Off-site environment

SABA	Jordan	n/a	Site Energy efficiency Water efficiency Materials Indoor environmental quality Waste and pollution Cost and economic
IBEAM	Ireland	1996	Energy use Indoor Environmental Quality Environmental loadings Site & transport Water & Waste Materials
Ecoprofile	Norway	1998	External Environment Resources Indoor Climate
EcoEffect	Sweden	2000	Energy use Material use Indoor environment Outdoor environment Life cycle cost
STEP project	Poland		External environment Internal environment Environmental aspects Economic analysis
Protocollo ITACA	Italy	2003	Outdoor Environmental Quality Resource Consumption Loadings Indoor Environmental Quality Quality of Service -Management Quality Transport
DGNB®	Germany	n/a	Ecological quality Economic quality Sociocultural and functional quality Technical quality Process quality Site quality
LiderA	Portugal	2000	Site and Integration Resources Environmental Loading Environmental Comfort Socioeconomic Experience Sustainable Use
LOTUS	Vietnam	2008	Energy Water Materials Ecology Waste & Pollutions Health & Comfort Adaptation & Mitigation Community Management
Estimada	United Arab Emirates	2010	Integrated Development Process Natural Systems Livable Communities Precious Water Resourceful Energy Stewarding Materials Innovating Practice

n/a – not available

The amount of information and tools is available to assist designers and builders in incorporating sustainable technologies and design strategies in their projects. In relation to existing tools, many reports [22, 27] present a description of the characteristics of a number of evaluation tools which are used for building and building materials, nationally and internationally.

III. Development and Presentation of the proposed Assessment System

In recent years, the evaluation of building performance in terms of environmental, social and economic aspects has become a topic of discussion in the Slovak Republic, as well. The new building environmental assessment system (BEAS) has been developed at the Institute of Building and Environmental Engineering, Technical University of Košice. The systems and tools used in many countries have been the foundation of the new system development applicable under Slovak conditions, mainly the SBTool. The main fields and relevant indicators of BEAS have been proposed on the basis of available information analysis from particular field of the building performance in Slovakia and also according to our experimental experience. The manner and form of indicators evaluation are proposed according to the SBTool. The proposal of the main fields results from the quality of the outdoor and indoor environment, nature and landscape conservation, exploitation of natural resources and so on. Building construction is subject to environmental deterioration, hence the proposal of site selection and project planning field is valid in BEAS. In Slovakia, buildings are characterized by high energy consumption therefore the energy performance is also an important field of assessment. Selection of building materials and structures is very important in terms of embodied energy and emissions of pollutants. BEAS as a multi-criteria system includes environmental, social and cultural aspects. The proposed fields and indicators respect and adhere to Slovak standards, rules, studies and experiments. In this study, the presented system has been developed for the preliminary stages of the life cycle, i.e. pre-design and design. The developed assessment system for Slovakia contains 6 main fields and 52 indicators.

TABLE II Proposed field, sub-fields and indicators in BEAS

Fields, Sub-Fields and Indicators		
A	**Site Selection an Project Planning**	
A1	Site selection	A1.1 Selection of ecologically valuable or sensitive land A1.2 Selection of land vulnerable to flooding A1.3 Selection of land near to a water object A1.4 Selection of Brownfield lands A1.5 Distance to road-traffic infrastructure A1.6 Distance to commercial and cultural facilities A1.7 Distance to public green space A1.8 Distance to engineering (utilities) networks A1.9 Possibilities of renewable energy sources utilization A1.10 Applicable orientation to maximize passive solar potential
A2	Site development	A2.1 Development of density A2.2 Possibility of change of building purpose A2.3 Relationship of design with existing streetscapes A2.4 Policies governing use of private vehicles A2.5 Guarantee of sufficient public green space A2.6 Use of trees for solar shading and sequestration of CO_2 A2.7 Maintenance or development of wildlife

		corridors
B	**Building Construction**	
B1	Materials	B1.1 Product environmental labeling B1.2 Use of materials that are locally produced B1.3 Use of recycled materials B1.4 Use of substitutes in concrete B1.5 Radioactivity of building materials
B2	LCA	B2.1 Primary energy embodied in building materials B2.2 Global warming potential B2.3 Acidification potential
C	**Indoor Environment**	C1 Thermal comfort during the heating season C2 Thermal comfort during the cooling season C3 Ventilation C4 Noise attenuation through the exterior envelope C5 Noise isolation between primary occupancy areas C6 Daylighting C7 Shading and blinds C8 Artificial lighting C9 Interior materials C10 Pollutant migration between occupancies
D	**Energy Performance**	
D1	Operation Energy	D1.1 Energy for heating D1.2 Energy for domestic hot water D1.3 Energy for mechanical ventilation and cooling D1.4 Energy for lighting D1.5 Energy for appliances
D2	Active systems on using renewable energy sources	D2.1 Solar system/heat pump D2.2 Photovoltaic technology D2.3 Heat recuperation
D3	Energy Management	D3.1 System of energy management D3.2 Operation and maintenance
E	**Water Management**	E1 Reduction and regulation water flow E2 Surface water run-off E3 Drinking water supply E4 Using filtration “grey water”
F	**Waste Management**	F1 Plan of waste disposal originated in construction process F2 Measures to minimize waste resulting from building operation F3 Measures to minimize emission resulting from building construction and demolition

A. *The Methodology of the Derivation of Assessment Field in System BEAS*

The methodology of the derivation of assessment field in BEAS has been performed according to a study [28]. A field list has been derived by a three-step process. In order to establish a comprehensive set of fields of the building environmental assessment method for office buildings, a combination of reviewing existing methods of building environmental assessment used worldwide, valid Slovak standards and codes, and an academic research paper has been conducted. A three-step process has been conducted in this method. The first step, a full range of fields relating to the sustainable building efficiency, has been collected through a wide-ranging literature review. In Step 2, a draft indicator list has been selected from the full indicator list based on an in-depth analysis. In Step 3, a questionnaire survey has been conducted in order to get the comment from the experts to refine the draft indicators. As a result, a final indicator list has been proposed. The figure (Fig. 1) shows final weights of main fields of assessment in BEAS.

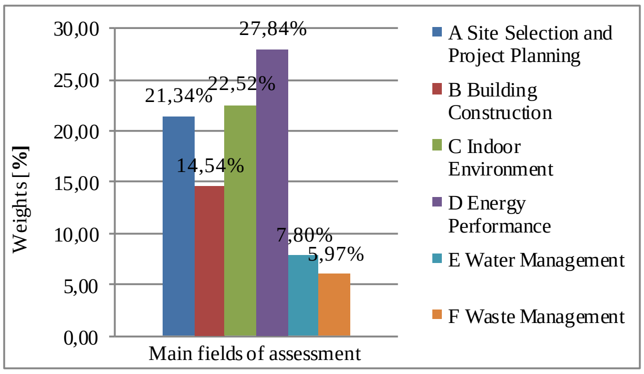

Fig. 1 Weights of main fields of assessment in BEAS

IV. Testing of the Assessment of the Tool

In the case of sustainable buildings, the details of energy consumption and the environmental effects of the building are performed using a Life Cycle Analysis (LCA). LCA considers the energy and environmental effects of the buildings, its systems, elements and materials starting from the extraction through production and use to the end-use. Embodied-energy analysis is a very important part of the consideration. In sustainable-building analysis, stress is put on three most important “flows” through a building, i.e. energy, water, and materials [29]. The idea of conservation is true for energy as well as for water and materials. Designers of buildings and their services take into consideration the role of these three components in the process of building planning, construction, use and decomposition (not demolition). In a sustainable-buildings strategy, we can find all the elements of energy efficient and environmentally-friendly buildings. In addition, stress is put on promotion of quality, which includes: quality of the indoor environment; quality of the residential area; quality of building materials [30]. Environmental quality has become increasingly influenced by the built environment and buildings play an important role in energy consumption and CO_2 emissions through phases of life cycle. The building construction sector consumes much energy and emits large quantities of carbon dioxide to the air. Embodied energy consumption and embodied CO_2 emissions of materials are essential indicators for sustainability in construction [31]. If the building was still at the design stage, a number of measures could have been taken in order to enhance the energy efficiency and hence reduce the electricity consumption of the building. Some of the available options include: enhancing the insulation of the external walls and the roof of the building, using fluorescent lights instead of the less-efficient incandescent lamps [32]. Building environmental assessment systems and tools have been developed for various types of buildings and for each phase of their life cycle. Comparison of methods used and tools is difficult making it possible to suggest that the approaches of these methods are principally not very different. Several differences are found in terminological expression, and in some of them the different indicators are assessed under the same areas. Again the methods of impact rate classification are also different and mostly respect their national conditions and requirements. They cover the building's life cycle differently. The method sensitivity can also vary and the indicators' independence is not always secured. A good building environmental assessment therefore requires a multidisciplinary and multi-criteria approach.

B. *Assessment of Building Construction*

The quality of the built environment also affects its inhabitants in many ways and is dependent not only on the architectural form and specification, but also on the quality and nature of materials used, the care taken in construction, the quality of building services design and components, and the timely and effective maintenance of the building fabric and support systems. A major factor in the development of building materials is that new structures are being asked to perform increasingly multifaceted tasks. In addition to their traditional load-bearing capacities and use as room partitions, building materials also need to fulfil a multitude of additional functions today. Along with technical criteria, economic and environmental criteria have become increasingly important factors when choosing and developing building materials. Materials with the smallest possible environmental impact (such as low levels of toxic emissions or required primary energy) are considered sustainable and suitable for use in the future [33]. Environmentally friendly building materials and constructions are intended to reduce energy and material flows during the entire building life cycle. The evaluation is focused on the assessment of consumption and depletion of material resources, especially non-renewable resources, to minimize the life-cycle impact of materials on the environment and enhance the indoor environmental quality by concentrating on the evaluation of energy flows through the building constructions. The proposed subfields and indicators of building construction fields are presented in Table 3. The evaluation of this indicator is determined according to the percentage, by weight, of environmentally friendly building products that are incorporated in the evaluated building. The proposed indicators in this main field of assessment respect Slovak standards, rules, studies and experiments [34].

TABLE III FONT SIZES FOR PAPERS

B	**Building construction**	**Weights [%]**
B1	**Materials**	**75 %**
B1.1	Product environmental labelling	18,77 %
B1.2	Use of materials that are locally produced	24,77 %
B1.3	Use of recycled materials	30,46 %
B1.4	Use of substitutes in concrete	15,07 %
B1.5	Radioactivity of building materials	10,92 %
B2	**LCA**	**25 %**
B2.1	Primary energy embodied in building materials	33 %
B2.2	Global warming potential	33 %
B2.3	Acidification potential	33 %

C. *Way of Assessment*

Each main field has several indicators 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 is obtained so that the point from scale is multiplying with weight of indicator. To support BEAS, a software tool enabling comprehensive evaluation of buildings was developed. The software tool for BEAS is based on the international software tool in Microsoft Excel for building environmental assessments – SBTool. The tool has nine evaluative lists. The first evaluative list serves as the identification for the assessed building. The register of main fields and determining indicators is in the second evaluative list. In the next six evaluative lists are main fields of assessment. The result is presented in last evaluative list in form of column graph and comprehensive tables.

D. *Office Buildings Assessment*

The evaluated office buildings were assessed in the phase of design according to available documentations, mainly drawings. The assessment was performed by software tool for BEAS prepared in MS Excel. Office building marked as 1 is located in Snina, 2 is located in Spišská Nová Ves, 3 is located in Košice, 4 is located in Michalovce, 5 is located in Bardejov, office buildings marked as 6 – 7 and 9 are located in Košice, office building marked as 8 is located in Bardejov. The figure (Fig. 2) shows average result of assessment selected office building in main fields of assessment according program BEAS. In first assessment field – Site selection has been achieved average result for nine assessment office building 1.91 from 5 point. In second assessment field – Building construction has been achieved average result 1.17 point. The best result has been achieved in third main assessment field – Indoor environment 3.02 point. In fourth main assessment field – Energy performance has been achieved average result 1.66 point. In fifth assessment field – Water management has been achieved average result 2.23 point and in last main assessment field has been achieved result 1.72 point from 5 point.

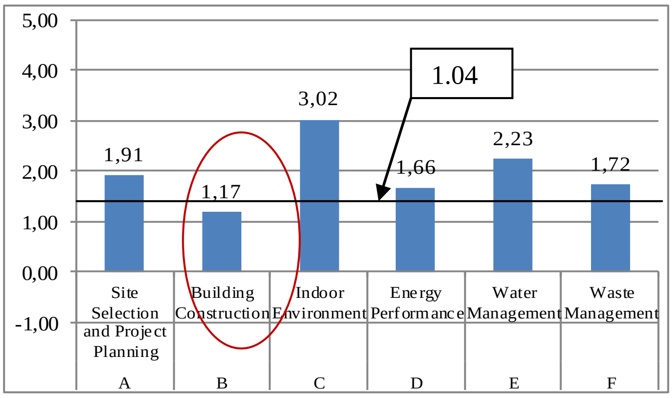

Fig. 2 Average result of assessment selected office buildings in main fields of assessment

The total weighted building score is 1.04 which is classified as environmentally acceptable building on the base of classification key shown in the table (Table 4). The results from the comprehensive environmental assessment of selected offices it can assert, that it is necessary to propose measures to improve the environmental suitability and safety of the evaluated office buildings in all assessed fields. The figure (Fig. 3) shows detail result of assessment of selected office building in second main field – building construction. The office building has been assessed in design process according to drawing documentation. The best result achieved office building number 7 with result 2.32 point from 5. The worst result in field of Building construction achieved office building number 8 – 0.13 point.

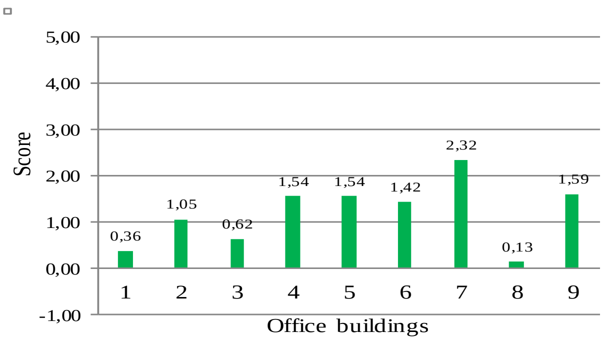

Fig. 3 Detail result of assessment selected office buildings in field of building construction

TABLE IV CLASSIFICATION KEY

Score	-1	0	3	5
Category	Environmentally unacceptable building	Environmentally acceptable building	Environmentally friendly building	Sustainable building

V. CONCLUSION

In the past decade, building environmental assessment systems, methods and tools have been developed and used in different countries for evaluating the sustainable and environmental performance of buildings. Building environmental assessment is a specific complex of proceedings oriented towards systematic and objective evaluation of a building's performance. These processes lead to the design, construction and operation of buildings with respect to criteria for sustainable development. The building environmental assessment is not only a tool for control, but also a tool of sustainable building design. The purposes of building assessments from environmental aspects are due to the determination of real building states from a safety and reliability point of view, the possibility of building comparisons, the effect of environmental buildings potential and the proposal of measures resulting in sustainable buildings. This paper introduced the system BEAS developed in Slovakia. The paper also presents a comprehensive method of identifying indicators for assessment in office buildings applying feasibility, completeness, effectiveness and multi-attribute decision making rules. The percentage weights of significance were determined for proposed sub-fields and relevant indicators. For the purpose of next system verification, a statistically significant set of buildings is required to be evaluated. The outcome from the system verification will be result in the modification of indicators weighting.

ACKNOWLEDGMENT

This study was supported by the Grant Agency of Slovak Republic to support of project No. 004TUKE-4/2011.

REFERENCES

[1] R. Mateus and L. Braganca, Sustainability assessment and rating of buildings: Developing the methodology SBToolPT–H. *Building and Environment* (46)10, p. 1962-1971.

[2] H. A. Hikmat, F. A. N. Saba, Developing a green building assessment tool for developing countries – Case of Jordan. *Building and Environment* 44 (2009), p. 1053-1064.

[3] R. J. Cole. Emerging trends in building environmental assessment methods. *Building Research & Information* 26 (1), p. 3–16, 1998.

[4] A. Dimitris, e. Giama, a. Papadopoulos. An assessment tool for the energy, economic and environmental evaluation of thermal insulation solutions, *Energy and Buildings* 41, pp. 1165–1171.

[5] I. Korolijaa, L. Marjanovic-Halburdb, Y. Zhanga, I. Hanbya, Influence of building parameters and HVAC systems coupling on building energy performance. *Energy and Buildings*, 43, pp. 1247–1253, 2011.

[6] A. H. Neto, f. A. S. Fiorelli, Comparison between detailed model simulation and artificial neural network for forecasting building energy consumption. *Energy and Buildings*, 40 (12), pp. 2169–2176, 2008.

[7] A. Mwasha, r. G. Williams, j. Iwaro, Modeling the performance of residential building envelope: The role of sustainable energy performance indicators. *Energy and buildings* (2011).

[8] IEA (2001). Energy related environmental impact of buildings.

[9] EU Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the Energy Performance of Buildings, Official Journal of the European Union L 153/13.

[10] P. Geyer, Systems modelling for sustainable building design, Advanced Engineering Informat. (2012),

[11] S. H. Alzami, Y. Rezguri, Sustainable building assessment tool development approach. Sustainable Cities and Society. In press http://dx.doi.org/10.1016/j.scs.2012.05.004 (accessed July 2012)

[12] I. Cooper, Which focus for building assessment methods – Environmental performance or sustainability? *Building Research & Information*, 27 (4–5), 321–331, 1999.

[13] D. Crawley, I. Aho, Building environmental assessment methods: Applications and development trends. Building Research and Information, 27 (4–5), 300–308, 1999.

[14] N. Kohler, The relevance of Green Building Challenge: An observer's perspective. *Building Research & Information*, 27 (4–5), 309–320, 1999.

[15] BREEAM. BREEAM New Construction. Non-Domestic Buildings. Technical Manual. SD5073-2.0:2011

[16] CASBEE. CASBEE® for New Construction. Technical Manual (2010 Edition). Japan Sustainable Building Consortium.

[17] R. J. Cole, D. Rousseau, G. T. *Theaker, Building environmental performance assessment criteria* (BEPAC)., 1993.

[18] LEED 2009 for new construction and major renovations. For public use and display. USGBC Member Approved November 2008 (Updated November 2011), p. 117

[19] BEAM Plus. BEAM Society. Building Environmental Assessment Method. NB – New Buildings, p. 219, 2009.

[20] Estidama. *The Pearl Rating Syastem for Estidama. Comminity Rating System*. Design & Construction. http://estidama.org/

[21] G. K. C. Ding, Sustainable construction: the role of the environmental assessment tool. *Journal of Environmental Management*, vol. 8, no. 1, 2008, p. 451-464

[22] S. Seo et al. Wang, *Technical Evaluation of Environmental Assessment Rating Tool*. 2005, p. 103

[23] WBDG. Whole Building Design Guide. http://www.wbdg.org/

[24] WGBC. World Green Building Council. www.worldgbc.org

[25] D. Castro-Lacouture et al, Optimization model for the selection of materials using a LEED-based green building rating system in Colombia. *Building and Environment* 44 (6) p. 1162-1170.

[26] A. Singh et al. Key issues in life cycle assessment (LCA) of ethanol production from ligneocelluosin biomass. *Bioresour Technol*, vol. 101, p. 5003-5012, 2010.

[27] W. B. Trusty, S. W. Horst, *Integrating LCA Tools in Green Building Rating Systems*. The Austin Papers: Best of the 2002 International Green Building Conference.

[28] Y. Yang, B. Li, R. Yao. A method of identifying and weighting indicators of energy efficiency assessment in Chinese residential buildings. *Energy Policy*, Vol. 38, p. 7687-7697, 2010.

[29] D. Anink, Ch. Boonstra, J. Mak. *Handbook of sustainable building. London:* James & James Ltd., 1998.

[30] D. Chwieduk, Towards sustainable-energy buildings. *Applied Energy* 76 (2003) 211–217

[31] L. Sheng-Han, A. Hasim, Environmental impact of building structures in Taiwan. *Procedia Engineering* 21, p. 291-297.

[32] H. M. Taleb, S. Sharples. Developing sustainable residential buildings in Saudi Arabia. *Applied Energy* 88, 2011, p. 383-391.

[33] F. Dehn, A. König, K. Pistol, *Technology Guide. Building Materials*. Springer, 2009.

[34] E. Krídlová Burdová, S. Vilčeková, Environmental assessment of building materials and constructions. *Applied Mechanics and Materials*. Vol.. 174-177 (2012), p. 3161-3165.

Eva Krídlová Burdová was born in Snina, Slovakia, 14th December 1981. In June 2006 was graduated at Faculty of Civil Engineering at Technical University of Košice. In October 2009 was achieved title PhD. at Institute of Environmental Engineering at Faculty of Civil Engineering in Košice, Slovakia. Since October 2009 works as an assistant professor at Institute of Environmental Engineering at Faculty of Civil Engineering in Košice, Slovakia.

Silvia Vilčeková was born in Košice, Slovakia, 12th February 1973. In June 2000 was graduated at Faculty of Civil Engineering at Technical University of Košice. In 2003 was achieved title PhD. at Institute of Environmental Engineering at Faculty of Civil Engineering in Košice, Slovakia. Since 2003 works as an assistant professor at Institute of Environmental Engineering at Faculty of Civil Engineering in Košice, Slovakia. Since 2009 works as an associate professor at Institute of Environmental Engineering at Faculty of Civil Engineering in Košice, Slovakia.