Sustainability Assessment of Buildings

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***Abstract*—This paper deals with the proposal of a building environmental assessment system (BEAS), especially one dealing with the assessment and weighting of the indoor environmental quality of office buildings in Slovakia. Percentage weights of fields and indicators are determined according to their significance, by multi-criteria decision analysis (MCDA). Finding from the study include proposal of field for indoor environmental quality of office buildings. Our future research work will be an implementation of aspects and indicators given in European standards for the sustainability assessment of buildings to the BEAS applicable in Slovakia and a comparison of BEAS with significant and globally used systems. Building environmental assessment system is used for conceptual solutions in the design and implementation of sustainable buildings. It is a tool for determining the cost of property or according to results of integrated assessment of buildings will be adjusted rent. Building environmental assessment is the basis for demonstrating greater credibility investor and owner of the building and the provision of credit products. The contribution of paper lies in proposal of evaluation of indoor environmental quality as a significant field of environmental assessment system for office buildings in Slovakia.**

Keywords—sustainable buildings, IEQ, assessment system, BEAS

I. INTRODUCTION

Building environmental assessment systems aim at considering the three aspects of sustainability of buildings: environmental issues such as greenhouse gas emission and energy consumption, economic aspects such as investment and equity and social requirements such as accessibility and quality of spaces [1]. According to WBDG Sustainable Committee [2], the main goals of sustainable design are to reduce depletion of critical resources like energy, water, and raw materials; prevent environmental degradation caused by facilities and infrastructure throughout their life cycle; and create built environments that are safe and productive [3]. Sustainability is increasingly becoming a key consideration of building practitioners, policy makers, and industry alike, since the world is moving towards green construction [4]. According to study of Sussman [5] green buildings utilize techniques, materials, and methods aimed at reducing the building's negative impact on the environment, while increasing the level of comfort, health, and productivity of its occupants [4]. Energy consumption of buildings depends significantly on the criteria used for the indoor environment and building design and operation. Environmental factors that define the indoor environmental quality are: thermal comfort, indoor air quality, acoustic comfort and visual comfort [6]. In the past decade, integrated assessment systems, methods and tools have been developed and used in different countries for evaluating the sustainable performance of buildings. A new Building Environmental Assessment System (BEAS) [7] has been developed at the Institute of Environmental Engineering, Technical University of Kosice. Proposed indicators respect Slovak standards and rules. 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. Percentage weights of fields and indicators are determined on the basis their significance, according to multi-criteria decision analysis. Proposed fields are site selection and project planning; building construction; indoor environmental quality; energy performance; water and waste management. Indoor environmental quality (IEQ) as one important field in sustainable assessment of buildings effects the health, productivity and well-being of building occupants, as well as lifecycle costs, and energy consumption. The goal of this paper is the proposal of BEAS, especially the assessment and weighting of the indoor environmental quality of office buildings in Slovakia.

II. REVIEW OF RELATED LITERATURE

In the developed parts of the world people spend almost 90% of their time indoors [8, 9]. Indoor conditions have therefore far-reaching implications for their health, general well-being and performance [10]. In recent years, there has been increased focus on the way in which different indoor climate factors affect employee performance [11]. In indoor environment, a number of physical and chemical factors have been identified that influence the comfort of building occupants. Standards dealing with indoor environmental quality have been developed to define the acceptable ranges of these parameters. Even though the requirements of these standards are met, not all building occupants are satisfied with the indoor environment. The same indoor environmental conditions may lead to different subjective responses. One obvious reason is that people differ and therefore not all are satisfied by the same conditions. Another reason could be that not only physical conditions influence satisfaction with the indoor environment. There may also be other factors, unrelated to indoor environmental quality, such as personal characteristics of building occupants (gender, age, country of origin etc.), building-related factors (room interior, type of building and control over the indoor environment) and the outdoor climate (including seasonal changes) that influence whether the indoor environment is considered to be comfortable or not [10]. There are also a number of objective performance measures that can be used [12]. Office work entails a wide range of different tasks involving a complex set of component skills: rule-based logical thinking, open-ended thinking, vigilance, persistence, concentration, effectiveness, effort, responsiveness/alertness, communication, short-term memory, accuracy, adaptability/flexibility, motivation, comprehension/understanding, analytical skills, planning and organization [13]. Nowadays, attentions are increasingly drawn to the human–work environment interaction. Some building energy efficiency measures implemented to help mitigate climate change have the potential to improve and/or degrade indoor comfort conditions, indoor air quality, and people's health [14]. Building occupants often react in noticeably different ways under the same indoor environment, leading to a presumption that various personal or psychosocial factors beyond environmental parameters influence occupants' perception of the quality of indoor environment [15]. It is usually assumed that employees who are more satisfied with the physical conditions of their workplace are more productive [16]. Objective measurements are usually a measure of task performance, including primary task performance (a single task is performed and the productivity is recorded as its absolute value) and comparative task performance (two or more tasks are performed consequently and the productivity variations between the tasks are recorded). The advantage of objective measurements is that quantitative results can be obtained [17]. Task-related performance is significant affected by human perception of indoor air quality [18]. Subjective measurements, which aim to obtain the subjects' perception on their level of productivity by means of questionnaires and interviews, have gained support because people are likely to perform according to their feelings [17]. The use of questionnaires for the subjective assessment of the working environment allows collecting information in addition to that given by mere instrumental measurements, thus highlighting problems not easily detectable in other ways, such as those connected to local discomfort [13].

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) [19]. After that, other methodologies, such as the Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) [20] from Japan, the Building and Environmental Performance Assessment Criteria (BEPAC) from Canada [21], the Building Environmental Assessment Method (BEAM) [22] from Hong Kong, the Green Building Rating System (SABA) [23] from Jordan, Estidama[24] from Emirate and the Leadership in Energy and Environmental Design (LEED) [25] from the United States were developed and are currently widely applied. Very comprehensive inventories of available tools for environmental assessment methods can be found in Ding [26], in Seo et al., [27] the Whole Building Design Guide [3], and the World Green Building Council [2, 28, 29]. 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 their main field related to IEQ assessment and year of initiated is shown in table (Table 3.1) [7].

TABLE I. WORLDWIDE SYSTEM

System	Country	Initiated	Main fields related to IEQ
BREEAM	UK	1990	Health & Wellbeing
Green Globes	Canada	2004	Indoor Environment
LEED	USA	1998	IEQ
SBTool	28 coun.	1996	IEQ
NABERS	Australia	2001	Indoor environment
BEAM	Hong Kong	1996	IEQ
CASBEE	Japan	2001	Indoor environment
SABA	Jordan	n/a	IEQ
IBEAM	Ireland	1996	IEQ
Ecoprofile	Norway	1998	Indoor Climate
EcoEffect	Sweden	2000	Indoor environment
LiderA	Portugal	2000	Environmental Comfort
LOTUS	Vietnam	2008	Health & Comfort

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. A new building environmental assessment system (BEAS) has been developed. After fields and indicators were proposed, they were weighted using the Analytic Hierarchy Process (AHP) method.

III. Building environemntal assessment system in Slovakia

A Methodology of weighting

A field list in system BEAS has been derived by a three-step process according to the methodology of the derivation performed in study [30]. 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. First step in the three-step process was based on reviewing the existing building environmental assessment systems and indicators have been collected. Classification and certification of buildings differs from one country to another in accordance with national conditions and requirements. The sensitivity of methods and independence of indicators are progressively ensured with continuous modification and specification of methods and tools. It therefore follows that good building environmental assessment requires a multidisciplinary and multi-criteria approach. The amount of information and tools are available to assist designers and builders in incorporating sustainable technologies and design strategies in their projects. In relation to existing tools, reports [26] present a description of the characteristics for a number of evaluation tools which are used for buildings and materials, nationally and internationally. Second step was based on a selection of a draft field list from the full field list based on in-depth analysis. Final main assessment fields in BEAS and weights are shown in the table (Table 3.2).

The main fields and relevant indicators of building environmental assessment were proposed on the basis of available information analysis from particular fields of the building performance and also according to our experimental experiences. The foundation of system development was mainly based on the LEED, SBTool and HK-BEAM [31].As a result, a final list of fields has been proposed. The multi-criteria framework incorporates the consideration of environmental issues in a development and it will play an important role in the evaluation approach. To ensure that the indicators developed are applicable to the operations of the business it is necessary to verify and revise the indicators through fieldwork reviews and consultation with experts and stakeholders.

This series of verification/modification processes is repeated until a refined set of indicators is obtained that is both necessary and sufficient to monitor the sustainability performance of buildings [32].

TABLE II. System BEAS

Main Fields	**A**	Building Site And Project Planning	14.71%
	B	Building Construction	20.59%
	C	Indoor Environment	23.53%
	D	Energy Performance	26.45%
	E	Water Management	8.82%
	F	Waste Management	5.88%

In step 3, a questionnaire survey was conducted in order to get the comments from the group of participating experts to refine the draft fields. A questionnaire survey which aims to weight the final field of indoor environment assessment in system BEAS has been conducted with 10 experts working in the field of indoor environment quality. Their task was the determination of significance intensity of assessment indicators according to the ranking of importance of each evaluation indicators. Complete criterion significance weighting was determined by using of Median Absolute Deviation (MAD) method. MAD is well known statistical method that is mostly used in problem of decision between many independent opinions. According to Lee et al. [33] credit-weighting is the heart of all assessment schemes since it will dominate the overall performance score of the building being assessed. However, there is at present neither a consensus-based approach nor a satisfactory method to guide the assignment of weightings.

B Assessment of IEQ

The proposed indicators of assessment in field of Indoor Environment in system BEAS which is applicable in the conditions of Slovak Republic for assessment of existing office buildings are: C1 – Thermal comfort, C2 – Humidity, C3 – Acoustic, C4 – Daylighting, C5 – TVOC, C6 – Indoor air quality, C7 – Radon, C8 – NO_2, C9 – PM_{10}, C10 – Microbe, C11 – Performance and C12 - Perceived comfort.

Thermal comfort in office building is evaluated according to the average value of (Predicted Mean Vote (PMV). In range of -0,2 to +0,2 it is negative practice, in range of -0,5 to +0,5 is acceptable practice, in range -0,7 to +0,7 it is good practice and if is PMV index smaller than -0,7 and bigger than +0,7 it is best practice.

Humidity is evaluated as relative humidity. For relative humidity smaller than 20 % it is negative practice, more than 20 % to 30 % is acceptable practice, 30 % to 40 % is good practice and more than 40 % it is best practice. According to this scale is assigned the point from scale of assessment.

Acoustic in office building is evaluated according to Decree no. 549/2007 Coll. establishing details on the permissible values of noise, infrasound and vibration and on the requirements for the objectification of noise, infrasound and vibration in the environment. If the equivalent level of A sound is more than 40 dB is the practice negative (-1 point) and if the equivalent level of A sound is low than 40 dB is the best that be responsible assigned 5 point from assessment scale.

Daylighting in office building is evaluated according to the appropriateness of the level and quality of lighting illumination in lux. Negative practice is if the level of illumination and lighting quality is not suitable for the intended task, and is not adequate lighting the task (-1). Acceptable practice is if the ambient lighting system provides illumination level and quality of lighting adequate for the planned task in desktops areas, and provides a sufficient lighting for the task (0). Good practice is if the ambient lighting system provides illumination level and quality of lighting adequate for the planned task in desktops areas, and is insufficient for the task lighting for every 15 m^2 work area (3) and best practice is if the ambient lighting system provides illumination level and quality of lighting adequate for the planned task in desktops areas, and is insufficient for the task lighting for every 10 m^2 work area (5).

TVOC concentration in office building is evaluated according the European standard EN 15251:2007 Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics as follows: for TVOC emissions according to EN 15251 are more than 0.2 $mg/m^2.h$ is it the negative practice (-1), if concentration is smaller than 0.2 $mg/m^2.h$ it is acceptable practice (0) and if the concentration of TVOC is smaller as 0.1 $mg/m^2.h$ it is best practice (5). “Indoor air quality in office building is evaluated according the European standard EN 15251:2007” as follows: if the level of CO_2 in the air expressed in unit of ppm for energy calculations is bigger than 800 ppm - negative practice, 500-800 ppm - acceptable practice, 500-350 ppm - good practice and smaller than 350 ppm.

Radon in office building is evaluated according to Decree no.528/2007 Coll. establishing details on requirements to limit exposure from natural radiation as follows: if the EOAR is bigger than 200 Bq/m^3 - negative practice (-1) and if the EOAR is smaller than 200 Bq/m^3 - best practice (5).

Permissible concentration of NO_2 is determined by Decree no. 259/2008 Coll. establishing details of the requirements for indoor climate environment and the minimal requirements for a lower standard apartments and accommodation facilities as follows: if the concentration of NO_2 is higher than 200 $\mu g/m^3$ it is negative practice, for range of 100 - 200 $\mu g/m^3$ it is acceptable practice, for range of 25 - 100 $\mu g/m^3$ it is good practice as well as if the concentration of NO_2 is smaller than 25 $\mu g/m^3$ it is best practice.

Limit values of particulate matters PM_{10} in indoor air are also determined by Decree no. 259/2008 Coll. If the concentration of PM_{10} is higher than 50 $\mu g/m^3$; it is negative practice and if PM_{10} is smaller than 50 $\mu g/m^3$ it is best practice.

TABLE III. INDICATORS - PERFORMANCE AND PERCEIVED COMFORT

C	Indoor environment	23.53 % weight	
C11	Performance	5.59 % weight	
Intent	The effect of IEQ on performance of buildings´ occupants.	score	
Indicator	Correct performance		
Negative	The correct performance is:	<70%	-1
Acceptable practice		70 to 80%	0
Good practice		80 to 90%	3
Best practice		>90%	5
C12	Perceived comfort	10.54 % weight	
Intent	The effect of IEQy on perceived comfort of buildings´ occupants.	score	
Indicator	Comfort of buildings´ occupants		
Negative	Comfort of buildings´ occupants is:	Very uncomfortable	-1
Acceptable practice		Uncomforta-ble	0
Good practice		Slightly uncomfortable	3
Best practice		Comfortable	5

Microbe in office building is evaluated as mould and bacteria. Mould are assessed according the maximum concentration in KTJ.m^{-3} as follows: negative practice is for range of 501 - 2 000 KTJ/m^3, acceptable practice is for range of 101 - 500 KTJ/m^3, good practice is for range of 26 - 100 KTJ/m^3 and best practice for concentration of mould ≤ 25 KTJ/m^3. In case of bacteria they are assessed according to the maximum concentration in KTJ.m^{-3} as follows: negative practice is for range of 501 - 2 000 KTJ/m^3, acceptable practice is for range of 101 - 500 KTJ/m^3, good practice is for range of 51 - 100 KTJ/m^3 and best practice is for concentration of mould smaller or equal 50 KTJ/m^3. In the table (Table 3.3) the way of evaluation of selected indicators in field of Indoor Environment is shown.

Performance of occupants in office building is evaluated as correct performance. Perceived comfort in office building is evaluated according to comfort of buildings´ occupants. Performance is assessed by a method that uses simulated office tasks. Occupants perform three different tasks (text typing, mathematical calculation and learning memory test) to evaluate performance of occupants in monitored office buildings. Occupants´ performance is evaluated using indicator – correct performance (correctly solved tasks). Correct performance (%) – expresses the ratio of the correctly solved answers to the maximum number of answers. Occupants assess the perceived comfort by using questionnaires in office buildings. Comfort votes are cast on 4-point numerical scales - comfortable (0), slightly uncomfortable (1), uncomfortable (2) and very uncomfortable (3).

Each main field in system BEAS 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.

C Results of weighting of IEQ indicators in system BEAS

A questionnaire survey which aims to weight the final indicators in system BEAS has been conducted with the experts. Ten experts from the field of IEQ participated in the study. Their task was the determination of significance intensity of proposed assessment indicators according to relative importance. Consequently the order and weights of significance assessment indicators in main field of IEQ has been statistically determined.

In the figure (Figure 3.1) is show final set of indicators.

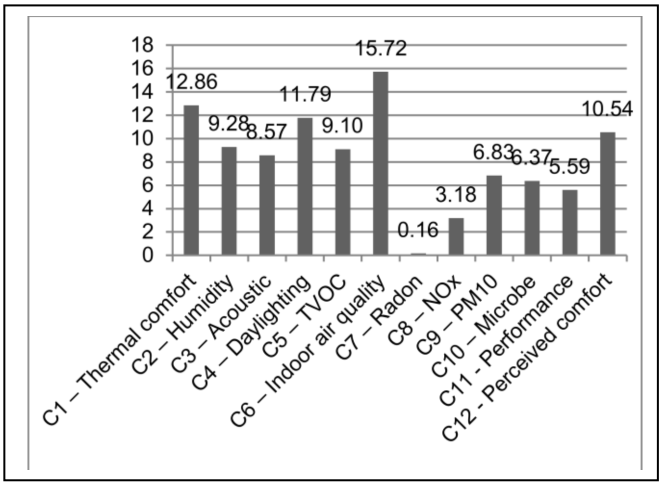

Fig. 1. *Indicators in field of IEQ and their percentage weights.*

IV. Discussions

Many studies are dealing with the assessment of buildings by internationally used or national systems and as state study [34] in many countries are developed or are in the process of developing national assessment methods, which makes the need for international exchange and coordination increasingly relevant.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 different building environmental assessment tools require varying amounts of data for the assessment of buildings. Methods of impact rate classification are also different and mostly respect the national conditions and requirements. In recent years, in Slovakia are certified buildings mainly by LEED. The purpose of this paper was introduced the development of building environmental assessment system in Slovakia. Secondly, study aimed at determination of significance weights of indoor environmental quality indicators for evaluation of office buildings. Each main field in system BEAS has several indicators which have the intent of assessment and the scale of assessment. Therefore the aim of this study is to highlight the need to certify buildings also by a national system as well as to analyse and compare the results from evaluation of buildings by different assessment systems. Methodology of system BEAS is intended to increase the sustainable residential buildings design, construction, operation and maintenance in Slovakia.

V. Conclusions

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 IEQ field and relevant indicators in system BEAS. Ten experts participated in the study. Their task was the determination of significance intensity of proposed assessment indicators according to relative importance. Consequently the order and weights of significance assessment indicators in main field of IEQ has been statistically determined. Our future research work will be an implementation of aspects and indicators given in European standards for the sustainability assessment of buildings to the BEAS applicable in Slovakia and a comparison of BEAS with significant and globally used building environmental assessment systems. For purpose of further system verification, a statistically significant set of buildings needs to be evaluated. The outcome from the system verification will result in the modification of fields and indicators weighting.

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