ASSESSING THE SUSTAINABILITY OF SERBIAN SCHOOL BUILDINGS BY ASPID METHOD

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Sustainable development indicators mainly provide information that can link the observed energy system with sustainable development. This paper considers building energy indicators in order to provide monitoring and measurement of energy performance of buildings. The results of measurement which are considered were obtained in school buildings in Serbia. The aim of this paper is to select, define, and calculate energy indicators as criteria for evaluating the quality of public buildings, with regard to sustainable development. The criteria for assessing sustainability are quantified by certain defined sets of economic, social and environmental indicators. The ASPID method of multi-criteria analysis is also described and mathematically presented. This method is based on the synthesis technique of fuzzy sets and the sustainability of the school buildings was based on their assessment as complex energy systems.

Keywords*: School buildings, Sustainable development indicators,Multi-criteria analysis, ASPID method*

1. Introduction

The public sector is one of the largest energy consumers at national and local levels. Energy use in the public sector usually refers to the energy consumption in administration, education, healthcare, culture and sports facilities, as well as energy consumption for public lighting and signaling, public transport, water treatment and water pumping stations. Buildings are responsible for 40% of energy consumption and 36% of CO_2 emissions within the European Union (EU) [1]. Policy-making and regulation relating to the supply and consumption of energy in the public sector often have an important role in the implementation of national energy policy. The necessary measures implemented to improve energy efficiency and rational energy consumption monitoring in schools, municipal and residential buildings can lead to the creation of new energy markets for technologies, the development of models that contribute to environmental protection, increases in benefits to the users of these institutions and the sustainable development of the wider economy and society.

Energy indicators for sustainable development in the field of building construction (schools and facilities for general purposes) form the basis for the implementation of energy efficiency policies. These indicators are then used to determine the effects of the implementation of energy efficiency measures and to assess the energy efficiency policy in terms of sustainable development. Moreover, energy indicators provide information describing energy flows in such a form that they can help making decisions at the national level [2,3].

Multi-criteria decision making or analysis is a generic term used for methods that help people to make decisions in cases when there is a trade-off between conflicting criteria (economic, environmental, social, technological). Two main schools have evolved that underline different approaches and methods in Multi-Criteria Decision Making: a) the 'European School' with the approach of “Multi-Criteria Decision Aid” (MCDA) and b) 'American School' with the approach of 'Multi-Criteria Decision Making' (MCDM). MCDM is based on the clear priorities of decision-makers. A clearly structured and optimized problem is solved in the mathematical process. MCDM methods have four basic steps that are supported in making the most effective decision: (1) Structure of the decision-making process, selection of options and criteria formulation; (2) Displaying a compromise between the criteria and determining the weight coefficients; (3) With regard to acceptable compromises an assessment of viability is carried out; (4) Calculating final aggregation and making a decision. MCDA as compared to MCDM, gives more importance in the final results, to the decision-making process, as opposed to the mathematical process. In the literature, there are several approaches that classify MCDA methods: Multi-Objective Decision-Making Method (MODM) and Multi-Attribute Decision Making Method (MADM) [4]. MADM is the most used in which the number of alternatives is pre-determined and limited. The main goal of MADM is to classify and select the alternative (rank) that is best rated according to the set of criteria (indicators) for evaluation. Within this model, information with additional data is combined in the decision matrix to obtain a ranking list or select one of the alternatives [5]. In the case of MODM, unlike MADM, no alternative is given in the decision-making process. MODM provides a mathematical framework for obtaining alternatives in decision making. Each once defined alternative is evaluated in relation to how well one or more criteria are met. The number of potential alternatives can be large and the solution implies a selection of options.

The commonly used MCDA methods in the field of energy sustainability are [6,7]: Analytic Hierarchy Process (AHP) [8], The Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS) [9], Elimination and Choice Expressing Reality (ELECTRE) [10], Preference Ranking Organization method of Enrichment Evaluation (PROMETHEE) [11], and Multi-Attribute Utility Theory (MAUT) [12].

The early history of MCDM started to emerge about 50 years ago and now many papers have explored the advantages and disadvantages of these methods. In [13] the authors analyzed and assessed a group of MCDM methods in 271 papers from the published literature. Fifteen MCDM methods were identified and are grouped into 5 large clusters. However, the hybridization of these groups was identified, including preferences of the stakeholders in regard to the criteria and indicators approach. [14] provide guidance and reviewed of MCDA methods. Numerous environmental applications of these methods are cited. A generalized framework which summarizes the complexity and multi-dimensional nature of the system in order to support the decision-makers is provided. The aim of paper [15] is to present energy consumption indicators for public building (administration and schools) based on accurate and reliable data. Specific indicators of annual energy consumption in offices, schools and healthcare facilities were obtained from data collected from 27 hospitals and 11 schools which had been renovated. In long-term energy planning, energy indicators can help in the decision-making process. Mwasha et al. [16] analyzed sustainable energy performance indicators as tools in the decision-making process. In order to assess sustainable energy performance of envelope, several aspects of sustainability assessments have to be taken into the consideration.

The aim of this study is to determine the quality indicators of sustainable development,the respective formation of sets of sustainable development indicators and calculation of a buildings index of sustainability using the MCDM method. To quantify the criteria for assessing viability, sets of indicators have been formed on the basis of statistical input data as well as data obtained by measurements. The economic, social and environmental indicators are defined, formed and calculated for two school buildings: 'The College of Textile Design Technology and Management' (DTM) which is located in Belgrade and the primary school 'Ljubica Radosavljevic Nada' in Zajecar (LJNR-Zajecar). After the formation of indicators, using the ASPID (Analyse and Synthesis Parameters under Information Deficiency) method, analyzing the school buildings as complex energy systems, a building sustainability index (IS) was calculated.

2. Energy efficiency, eco-efficiency, and sustainable development

Energy consumption has increased over a large section of the residential and non-residential sector in Serbia. In the recent times, increasing expenditure of thermal energy and energy for cooling buildings, due to the increasing average temperatures during the summer months have also been noted. Energy consumption for heating in buildings with average thermal insulation in Serbia constitutes about 60% of total energy consumption. The main reasons which affect the increasing thermal energy consumption are the duration of the heating season and the required indoor air temperature which depend on climatic conditions and space quality standards. The quality of the mechanical heating systems, the total heated area, and the isolation of the building also have a significant impact.

Electricity and thermal energy consumption in schools depend on various factors such as the condition of the buildings (woodwork, roof, thermal insulation ...), the energy source for heating, the efficiency of the devices, the number of working hours, the number of degree days, the duration of the summer and winter holidays and the number of users. The main parameters which influence energy efficiency in schools are the lower level of construction quality, the age of the buildings and the lack of projects for refurbishment, insufficient maintenance, and inefficient use of heating and cooling systems.

Due to the growing demand for energy which affects environment quality on the community level, and indoor air quality on the building level, energy efficiency must be envisaged as part of eco-efficiency that is often used as an indicator to measure ecological sustainability, Figure 1 [17].

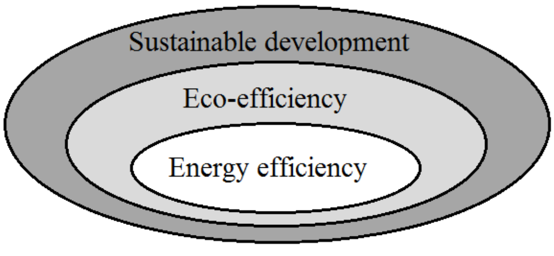


Figure 1 Energy efficiency, eco-efficiency and sustainable development

Implementation of measures to increase energy efficiency in buildings (schools, public and residential buildings) reduces energy consumption, increases indoor comfort and the life-cycle of the building. Moreover, significant contributions are made towards reducing dependence on energy imports, improving the security of energy supply and reducing emissions of greenhouse gases. The choice of measures depends on the energy situation, the type of building, how it is utilized and where it is located. The optimum is to implement several measures in order to obtain significant savings in energy consumption.

However, it is not enough just to make an energy-efficient building that will achieve energy savings, it is necessary to establish a link between energy requirements and indicators of indoor air quality. Chronic diseases, including respiratory diseases, are directly connected to an excessive pollution of indoor air.

This study presents and analyses the methodology of selection and formation of indicators of sustainable development in the building sector (schools), which is one of the main tools for implementing energy efficiency policy. It should be carried out at the national level in the framework of sustainable development policy, the harmonization of economic and social development and the limitation of environmental pollution.

2.1. Sustainable development indicators (SDI)

It is becoming obvious that the current indicators of social development are not sufficient and can not provide information about the real state of affairs in the social, economic and natural environment. Thanks to the development of information technology at the global level, the amount and availability of information in the field of sustainable development is rapidly increasing.

It is necessary to utilize this data effectively in the creation of social, economic, environmental and institutional policies for sustainable development, in order to facilitate high quality decision-making and the formation of system sets of SDIs. These help to better understand the different dimensions and aspects of sustainable development and the complex mutual relations between these aspects. SDIs offer useful information that can link the observed energy system with sustainable development.

The system can not move towards sustainable development if there is no clear, timely, accurate, appropriate and visible information. Although SDIs have to provide information on the sustainable development of an energy system, they must also be indicators of efficiency, sufficiency, equality, and quality of life. Indicators must be simultaneously relevant in two different areas: science and policy decision making. To be reliable and useful they have to be formed on a solid data base containing accurate and consistent statistical information.

Energy indicators go beyond the limits of basic statistics and are formed to assist our understanding of the main objectives and important relations that are not apparent when using basic statistics. These indicators provide a deeper understanding of the causal links between energy, environment, and economy, pointing out connections that are not readily apparent from the basic statistics [18]. Taken together, these indicators can give a picture of the whole energy system, including mutual connections and exchanges between the different dimensions of sustainable development, as well as the long-term consequences of current decisions and behavior. Changes in the value of such indicators over time, shows what progress has been made, if any, in connection with sustainable development.

The first step in evaluating the viability of any energy system consists of determining the boundaries of the system, in order to then determine the criteria for the assessment of system sustainability. Figure 2 shows the main boundaries of the selected building energy system: *a)* the thermal building envelope (an area that separates the indoor from the outdoor environment through which there is an the exchange of energy), through which there are different types of energy flows (fuels, district heat, and electricity); and *b)* the indoor environment where the actual energy services are delivered [19].

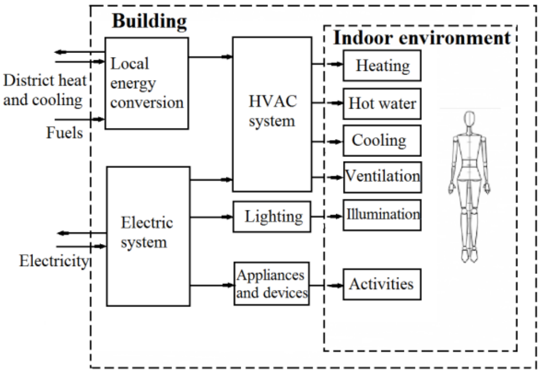


Figure 2 The system boundaries of a building [4]

There is no limit to the number of criteria (indicators) that can represent the characteristics of an energy system. A large number of indicators may not be more useful for assessing the energy system sustainability than a small number of criteria. In order to select an optimal number of indicators, and not to endanger the process of assessing sustainability, there are certain principles that need to be considered [20-22].

Among the selected indicators there are those which have a minor character. Therefore, it is essential to choosing indicators by some of the established methods such as the Delphi method, the method of least squares, the min-max deviation method or the correlation coefficient method. Furthermore, in order to compare and measure the sustainability of energy systems the criteria have to be normalized [23-25].

3. Defining and validating indicators of sustainable development

In this paper we select, define, and calculate indicators of sustainable development for two school buildings. The basic sets of indicators were calculated using databases obtained from measurements and existing reports in order to assess the energy efficiency and energy performance of buildings.

The primary school LJNR-Zajecar is one of the buildings analyzed (option 1). It is located in the municipality of Zajecar and, has a heated area and volume of 3,878.45 m^2 and 12,798.88 m^3, respectively. For space heating, thermal energy from coal (lignite) is obtained in a local heating system and for water heating, electricity is used, in sanitary hot water preparation system (SHWS). The school LJNR-Zajecar has 750 pupils and 70 employees. It was built in 1972 and so far has twice been renovated (1987-88, and 2007-2008), Figure 3. The building is moderately exposed to dominant winds. All classrooms and rooms in the school building are naturally ventilated Table 1.

Figure 3 Primary school'Ljubica Radosavljevic Nada' (LJRN)

Figure 4 The College of Textile Design and Management' (DTM)

The other school building that was analyzed in the process of SDI formation is DTM (Option 2) and, is located in Belgrade, Figure 4. The school was built in 1917 and, the heated area and volume are 1259.1 $m^2$and 4543.47 m^3, respectively. The school has 505 students and 35 employees Table 1. A district heating system is used for space heating. The local SHWS and space cooling system used electricity while ventilation is achieved naturally [26,27].

Table 2 displays information on the selected economic, social and environmental indicators and data sources. Sub-indicator numerical values are placed in Tables 3-5. In this paper, the economic indicator consists of the following sub-indicators set: Thermal energy for heating (I_{he}) is calculated on the basis of annual thermal energy for heating (energy passport) [28,29]. Delivered thermal energy is based on the results obtained by measurement (i.e. mass flow rate and temperatures of hot water); Electricity consumption per square meter (I_{ee}); Costs caused by losses in the heating system (I_{chs}), which is calculated on the basis of annual heat losses of the heating system. For Option 1 the heat source is coal (Hd=7850 J/kg) and for Option 2 the heat source is gas (Hd= 34 MJ/m3) from the district heating system; and the delivered primary energy per person (I_{pe}) which is calculated from annually delivered primary energy divided by the number of people (number of employees plus the number of students), Table 3.

The social sub-indicators set is given in Table 4: the number of employed persons (I_{ne}); annual hot water consumption(I_{shw}) the calculation of which is based on the annual energy use for SHW preparation and data about how much thermal energy is needed to heat 1 liter of water; and workspace per student(I_{ws})is calculated on the basis of the net useful heating area and the number of student.

Table 5 includes the following environmental sub-indicators: Particulate matters suspended in the indoor air, size up to 10μm (I_{PM10}). A sampling of PM_{10} was performed on the filters using pumps, and then the concentration of particulate matters was calculated based on the mass and flow; Formaldehyde emissions (I_{HCHO}), and nitrogen dioxide emissions (I_{NO2}). The concentrations of HCHO and NO_2 were measured using passive samplers (one sampler per pollutant). The sampling of pollutants from the indoor environment was performed at five measuring sites in case of LJNR and in seven measuring sites in case of DTM, [30-33].

Table 1 School buildings data

Some basic data on school buildings	*Primary school*: 'Ljubica Radosavljevic Nada' - Zajecar	*College*: Textile Design Technology and Management - Belgrade
Net useful building area (m^2)	3878.45	1259.10
Heated volume of building (m^3)	12798.88	4543.47
Total number of employees (-)	70	35
Total number of students (-)	750	505
Construction building year	1972	1917
Heating system and heat source	local - coal (lignite)	district heating - gas
System for SHWS and heat source	local - electricity	local - electricity
Ventilation	naturally	naturally

Table 2 Selected indicators and data source of economic, social and environmental indicators

Indicator	Unit	Definition	Data source
I_{he}	$kWht/m^2a$	Thermal energy for heating	Measured and calculated data
I_{ee}	$kWhe/m^2a$	Electricity consumption per square meter	Through the reports
I_{chs}	EUR/m^2a	Costs caused by the losses in the heating system	Calculated value, energy passport
I_{pe}	kWh/person	Delivered primary energy per person	Calculated value
I_{ne}	-	The number of employed persons	Through the reports
I_{shw}	l/a	Annual hot water consumption	Calculated value, energy passport
I_{ws}	m^2/pupil	Workspace per student	Calculated value, energy passport
I_{PM10}	$\mu g/m^3$	Respirable suspended particulate matters size up to 10μm	Measured and calculated data
I_{HCH}	$\mu g/m^3$	Formaldehyde	Measured and calculated data
I_{NO2}	$\mu g/m^3$	Nitrogen-dioxide	Measured and calculated data

Table 3 Numerical values of economic sub-indicators

Option	Economic indicator (I_{EC})			
	$\mathbf{I_{he}}$	$\mathbf{I_{ee}}$	$\mathbf{I_{chs}}$	$\mathbf{I_{pe}}$
	$kWht/m^2$	$kWhe/m^2a$	EUR/m^2	kWh/person
LJNR	185	10.65	3.2	1,953.91
DTM	101	3.46	0.47	288.47

Table 4 Numerical values of social sub-indicators

Option	Social indicator (I_{SC})		
	$\mathbf{I_{ne}}$	$\mathbf{I_{shw}}$	$\mathbf{I_{ws}}$
	-	l/a	m^2/pupil
LJNR	70	111,706.5	5.17
DTM	35	36,264.4	2.49

Table 5 Numerical values of environment indicator

Option	Environment indicator (I_{EN})		
	I_{PM10}	I_{HCHO}	I_{NO2}
	μg/m^3	μg/m^3	μg/m^3
LJNR	70.63	63.74	15.02
DTM	43.42	7.31	8.29

4. ASPID method of multi-criteria analysis

MCDM methods have become very popular and are particularly well-suited for assessing the multi-dimensional nature of energy systems from the aspect of sustainability [20,34-36].With a large number of MCDM models, the weight coefficients for the criteria (indicators) are based on subjective judgments (depending on expert' opinion), where the relative weight coefficients (w) are expressed numerically or use a linguistic rank scale.

This paper presents the use of the ASPID method of multi-criteria analysis in order to rank the options (school buildings) under consideration. In this process, decision-makers define priorities through the weight coefficients that represent a share in the final outcome. The ASPID method is a mathematical tool, unlike other methods, that provides an objective assessment of the weight coefficients since in the process of randomization the ambiguity of weight coefficients was determined. The weight coefficients of the criteria were mathematically defined by the mutual relation of each option and criterion at a pre-defined constraint. In the process of normalization of indicators, information that might be valuable at certain levels of assessment is not lost (as is the case with other methods). According to the different constraints (mutual relationship of different criteria) which is given over non-numerical, inaccurate and incomplete information, can be a useful tool in sustainability assessment. The ASPID method provides a better understanding and expression of results from the standpoint of the practical application of multi-criteria methods [23-25].

The normalization procedure of sub-indicators was selected in the case when different dimensions are aggregated in the general index that includes physical, social, economic and environmental data. Equation (1) shows that each value of sub-indicators x_i was transformed into normalized indicators that have values between 0 to 1:

$$I_{qi} = \frac{x_{ij} - \min(x_i)}{\max(x_i) - \min(x_i)} \qquad (1)$$

where are: x_{ij} is a single value of indicator i and option j; $min(x_i)$ and $max(x_i)$ are the minimum and maximum value of x_{ij}

After the normalization process, agglomerated sub-indicator values were obtained by linear aggregation function (Eq. 2) at the first level of calculation.

$$I_{agi} = \sum_{i=1}^{m} w_i \, q_i \qquad (2)$$

where: w_i are the weight coefficients of sub-indicators and q_i the normalized values of sub-indicators

The objective assessment of weights are determined and can have a significant effect on the overall composite indicator and ranking of the options. The weight coefficients are calculated within steps h=1/n, where n is a positive number of pieces of divided segments from 0 to 1. The set of all possible discrete components N(m, n) belonging to the set W(m, n) of all possible weights is calculated by:

$$N(m,n) = \frac{(n+m-1)!}{n!(m-1)!} \qquad (3)$$

where m is the number of initial specific criteria.

The second level of calculation includes pre-defined constraints that represent non-numerical information about the interrelation between criteria (Fig.5-8). Also, synthesis function for IS calculation is used:

$$\overline{IS(q;I)} = \frac{1}{N(I;m,n)} \sum_{s=1}^{N(I;m,n)} Q\left(q; w^{(s)}\right), \quad w^{(s)} \in W(I;m,n) \qquad (4)$$

where: $\overline{IS}(q;I)$ is the average value of index of sustainability; q is the normalized values of indicators; and I shows non-numerical, inexact and non-complete information.

5. Results and analysis

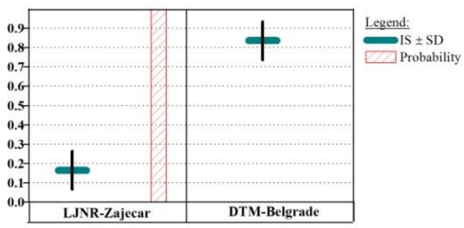
Assessment and sustainability analysis of the two school buildings (options) were performed following the established methodology of multi-criteria analysis. The proposed options that represent complex energy systems, are envisaged using the ASPID method based on stochastic valuation sets of indicators and sub-indicators thus allowing evaluation and calculation of IS.

CASE 1

This study analyzed four cases which are presented in Fig. 5-8. In Case 1 priority was given to the economic indicator (w=0.67) and sub-indicator of thermal energy for heating (I_{he}) while social and environment indicators (w=0.16) had the same importance. Figure 5 shows, based on the calculated values for IS, that Option 2 is a highly rated option (IS= 0.836, Sd= 0.099), while Option 1 (IO= 0.1643; SD= 0.099) is at the bottom of the priority list as very poorly ranked option.

Constraint: $I_{EC}(I_{he}>I_{ee}>I_{chs}>I_{pe}) > I_{SC}(I_{ws}>I_{ne}>I_{shw}) = I_{EN}(I_{PM10}>I_{HCHO}>I_{NO2})$

(a)



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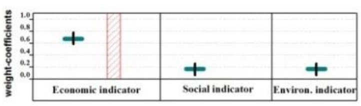


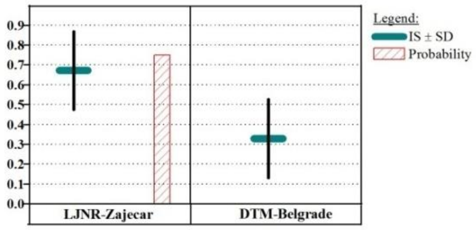
Figure 5 Sustainability of analyzed options for Case 1: (a) Index of Sustainability (b) Weight-coefficients

CASE 2

Case 2 considers the constraint when priority is given to the social indicator (w= 0.67) and social sub-indicator of the number of employees. Economic and environmental indicators are equal in importance. Figure 6 shows that Option 1 is the more suitable option as it is well ranked (SI= 0.671; Sd= 0.1978), while Option 2 (IS= 0.329; Sd= 0.1978) has a low sustainability level.

Constraint: $I_{SC}(I_{ne}>I_{ws}=I_{shw}) > I_{EC}(I_{chs}>I_{pe}> I_{he}=I_{ee}) = I_{EN}(I_{PM10}>I_{HCHO}>I_{NO2})$

(a)



(b)

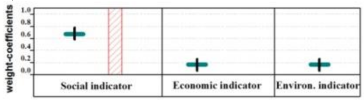


Figure 6 Sustainability of analyzed options for Case 2: (a) Index of Sustainability (b) Weight-coefficients

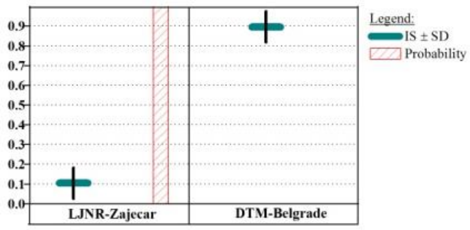
CASE 3

Figure 7 presents the situation when priority was given to the environmental indicator (w=0.62) over the economic indicator (w=0.28) and social indicator (w=0.1). In the process of sub-indicator agglomeration, the following sub-indicators have priority: formaldehyde, delivered primary energy per person, the annual energy use for the sanitary hot water preparation. Based on the pre-defined constraint for Case 3, unlike the previous cases, Option 1 has the lower IS=0.104(Sd= 0.0784) and Option 2 is placed at the top of the priority list (SI= 0.896; Sd= 0.0784) as the perfect option.

Option 1 uses coal as a fuel source for space heating and the measured value of formaldehyde level in primary school is significantly higher than recommended value (Table 5) [37] so it was estimated as the worst option for all cases.

Constraint: $I_{EN}(I_{HCHO}>I_{PM10}=I_{NO2}) > I_{EC}(I_{pe}>I_{ee}> I_{he}= I_{chs}) > I_{SC}(I_{shw}>I_{ws}>I_{ne})$

(a)



(b)

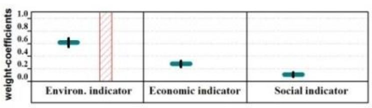


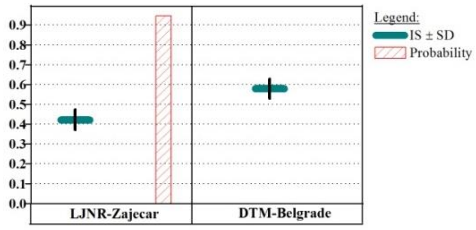
Figure 7 Sustainability of analyzed options for Case 3: (a) Sustainability Index (b) Weight-coefficients

CASE 4

When environmental and social criteria have equal importance (w=0.42) and priority economic criteria (w=0.16), as shown in Fig. 8, both options were estimated as well ranked. The calculation shows than the sustainability quality of Option 2 is slightly less than that of Option 1 (IS= 0.579; Sd= 0.0492 and SI= 0.421; Sd= 0.0493, respectively). For the defined constraint in Case 4, the following sub-indicators have priority: particular matter up to 10µm, nitric-dioxide and working space per student.

Constraint: $I_{EN}(I_{PM10}=I_{NO2}>I_{HCHO}) = I_{SC}(I_{ws}>I_{shw}= I_{ne}) > I_{EC}(I_{chs}>I_{pe}>I_{ee}=I_{he})$

a)



b)

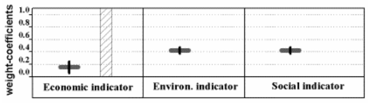


Figure 8 Sustainability of analyzed options for Case 4: (a) Index of Sustainability (b) Weight-coefficients

6. Conclusion

The first evaluation of buildings systems regarding sustainability criteria began in the last ten years of the 20th century. Before this system appeared, there was no objective and adequate manner to simultaneously assess the fulfilled a number of energy, environmental and social requirements according to clearly defined criteria and to provide a clear performance overview. Today, multi-criteria models based on different criteria, achieve a comprehensive assessment of the quality of different systems and evaluate the sustainability aspects of the solutions. Determination of the quality of the building in relation to the implementation of a number of defined criteria plays an important role in raising awareness about the importance of sustainable buildings and includes many experts from various fields to discuss the complex problems of sustainability.

In the long term settings of complex decision-making in energy policy from the sustainability aspect, this paper presents a mathematical tool for assessing the sustainability of complex energy systems that can integrate multi-dimensional parameters.

The aim of this study is to assess the quality or school buildings sustainability by the ASPID method. An examination of the influence of individual criteria (indicators), and their mutual influence on the formation of the priority list of options are described. Four cases are shown when priorities are given to different criteria. In Cases 1 and 3, where priority is given to economic and environmental criteria, Option 1 (primary school LJNR-Zajecar) was estimated as a low ranked option while Option 2 (DTM) is on the top of the rating list as a perfect option. Option 2 is well ranked for Case 4 when the environment and social indicators have equal importance and priority in accordance with the economic indicator. However, only in Case 2 when the social indicator has priority, did Option 2 have a low sustainability level and Option 1 was well ranked.

Further development in this field of research should be directed to the proper selection and development of criteria and the formation of extended databases to obtain greater accuracy in the formation of energy indicators.

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