SUSTAINABILITY ASSESSMENT OF RESIDENTIAL BUILDING ENERGY SYSTEM IN BELGRADE

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ABSTRACT

As a metropolitan city, Belgrade is a dwelling place for about 25% of total citizen number of Republic of Serbia, and at the same time regional cultural, educational, scientific and business center with its own energy production. Belgrade represents a significant consumer of final energy to support the living standard of the occupants. Energy production is based on domestic coal and imported fossil fuels such as oil and natural gas resulting in a high impact to the environment by emission of harmful substances.

Multi-criteria method is a basic tool for the sustainability assessment in metropolitan cities. The design of potential options is the first step in the evaluation of buildings. The selection of a number of residential buildings is based on geographic position and type of heating.

This paper presents the sustainable assessment of energy system for residential building sector in Belgrade. In order to present the energy system options for residential building sector, three sets of energy indicators: economical, social and environmental are taken into consideration.

INTRODUCTION

A strong need to improve the quality of life, from the beginning of mankind up to now, made human race to deeply alter his natural environment, stronger and more serious than any other creatures on our planet. Using his intellect, in order to meet his own needs, man developed a range of technologies for the production of various forms of energy. Unfortunately, most of our civilization depends on technologies that transform the chemical energy of fossil fuels in electricity and thermal energy. The amount of these sources decreases every day , their prices grow, while causing very serious environmental problems. There is a huge risk that all the stocks of coal, oil and gas, which are emerging during 500 million years ago, will dry up in a very short period of contemporary history of the world. Figure 1 shows the prediction of the potential duration of natural resources compared to the consumption in the late nineties of the last century [Afgan, N.H. et al.1998.].

As it is known, the energy resources are the basic building elements of our civilization [ISES NGO Renewable Energy Institute]. On the one hand, residual life of resources is decreasing, and on the other hand, energy needs are growing enormously with the growth of the world population and rapid economic development of developing countries. Unfortunately, the use of these resources is often associated with undesirable effects.

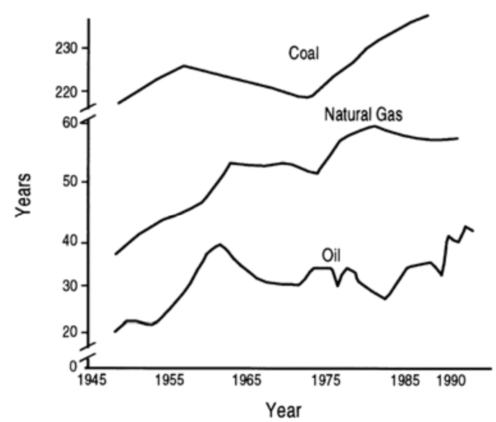

Figure 1. Residual life forecast of energy resources [Afgan, N.H. et al.1998.]

This is the reason why society recognizes the importance of intelligent energy use with a sensibility that the required energy services should be provided as clean and efficient as possible [Afgan, N.H. and Carvalho, M.G. 2000]. The existing building stock in European countries accounts for over 40% of final energy consumption in European Union of which residential use represents 63% of total energy consumption in building residential sector [Balaras, C.A. et al. 2007.]. Serbia is a mainly agricultural country with poor industry sector and even higher percentage of building sector share in total energy consumption (about 48%). Residential sector in Serbia is responsible for about 65% [Energy Efficiency Agency.2007.] of energy used in building sector which is 31.2% of total energy spending. Therefore, there is a large potential for energy savings in household sector through increasing energy efficiency of residential buildings, and thus to reduce emissions. On the other hand, there is economic inability of most of the population, lack of investment motivation due to improper parity of fuel and energy, as well as a normative heat payment for district heating.

In order to comply with economic development, environmental protection and living standards, there is a need to implement the concept of sustainable development, containing a multi-criteria approach. It is necessary to develop a methodology for assessing the sustainability of housing stock as an energy system, to its future planning development at the best possible way.

BELGRADE RESIDENTIAL BUILDINGS STOCK AS AN ENERGY SYSTEM

Belgrade is the capital of Serbia and the largest city in the Western Balkan, with about 1.7 million inhabitants in about 670,000 households. The city climate is between continental and temperate continental, and there are four seasons clearly distinguished, with frequent appearance of strong southeast wind during autumn and winter. Winter temperatures usually range between -5 º C and +2 º C and in summer often go over 30 º C. Energy is mainly consumed for heating in the winter, and in recent years, due to the increase of temperature in summer period, for cooling, too.

The city of Belgrade has a multiform architecture. In various parts of the city architecture varies from the typical Central European style (old town) to the modern architecture of New Belgrade, whose construction began in the sixties, when most houses were built quickly and cheaply with the lack of implementation of regulations for thermal building protection.

Cities are the largest energy consumers in a total energy production of a country. The annual growth of total primary energy consumption is about 3% where energy is mostly used for lighting, cooking, living space heating and cooling, and transport of people and goods. Large amounts of energy are lost due to inefficient spending in household, transportation and industry sectors. Figure 2 shows forecast of increase in the heat energy consumption in the period of 2010th-2020th in households and service sectors for the city of Belgrade [Jovanovic, M. at all, 2009.].

It is necessary to understand the importance of reducing energy consumption for the environment protection in urban areas. The energy efficiency of buildings is the first and basic step for a sustainable energy building management. Beside the traditional ways for increasing building efficiency (improvement of a building envelope thermal characteristics, modernization of thermal and power plants, automation, etc.), there is a need to introduce technologies for energy production which do not impair the quality of living environment.

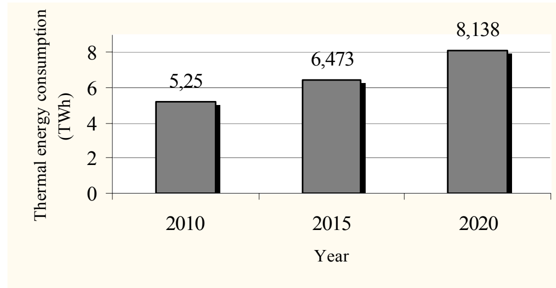

Figure 2. Predicted thermal energy consumption for the Belgrade Household and Service Sector [Jovanovic, M. at all, 2009.]

It is essential to find a balance between current and future energy needs and environment demands, preserving energy resources and clean the environment for the future generations [Chwieduk, D. 2003.]. The first step in development planning of a sustainable urban environment is to make assessment of its current sustainability index. This paper presents a methodology for sustainability index determination of the Belgrade housing stock based on three energy criteria: economic, ecologic and social.

OBJECTS

There is a consumption of different types of energy for the space heating in Serbia. The structure of consumption is primarily related to the cost of energy, and their availability on the market. The most common type of heating is definitely solid fuels burning (mostly coal) in the local furnaces and it is represented with about 50%. District heating and electricity heating each, are represented by 14%, houses with local solid fuel boilers by 12% and the natural gas heating by 10% of the total heat energy consumption (Fig. 3).

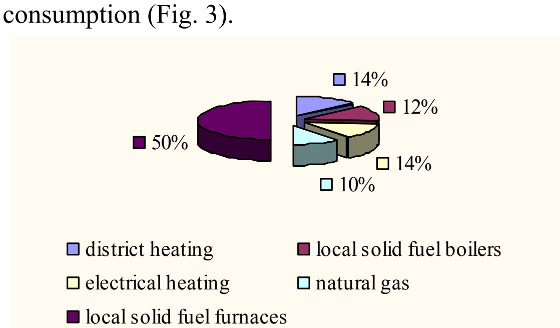

Figure 3. The ways of building heating in Serbia [Energy Efficiency Agency.2007.]

Regarding energy consumption for heating, there is a bit different situation in Belgrade. Approximately 38% of buildings are connected with district heating system, and in recent years, in order to reduce pollution, about 800 solid fuel boilers have been recently shut down [Jovanovic, M. at all, 2009.].

According to the lack of Belgrade city relevant statistical data, this work didn't intend to determine accurately the viability of the Sustainability Index of Belgrade housing energy system. The aim was to show the methodology for the determination. For this purpose, four residential buildings/houses were selected (object A, B, C and D) distinguished by location (placed in four different municipalities), heating type and construction quality.

The Object A (Fig.4) is located in New Belgrade and connected with city district heating system. It is a residential twenty-one-floor building in a windy part of the city, built in 1980. This object is constructed using big concrete blocks with no external walls isolation. From the thermal point of view, building is at level of very low quality.

Figure 4. The Object A photo

The Object B (Fig.5) is a four-floor building and it is also in the windy city area. Each apartment within the building is supplied with separate heating system using liquid petroleum gas as a fuel, provided from the central fuel tank. The object was built in 2006. External walls are made of two clay brick layers with isolating material in between and belongs to the high thermal quality buildings.

The Object C (Fig.6) is a single-floor house made of light construction (mainly wooden parts) placed in very far suburb in the not-so-windy area. House was built in 1976. and renovated in 2006. Specific type of heating appliances are used for house heating supplied with fans and bricks capable to accumulate the heat. This type of heating by electricity is one of the most common ways of heating with electricity in Belgrade. The object belongs to the medium quality in the way of construction. The external walls are made of wooden panels with isolating material in between.

Figure 5. The Object B photo

Figure 6. The Object C photo

The object D (Fig.7) is the two-floor house located in the far suburb, built in 1992 with external walls made of syporex blocks without isolation. It belongs to the poor thermal facilities. House is supplied with a coal stove for the space heating.

Figure 7. The Object D photo

ENERGY INDICATORS FOR THE SUSTAINABILITY ASSESSMENT OF RESIDENTIAL STOCK

Energy indicators for sustainable development are parameters which indicate the quality of the energy system. The criteria for assessing the sustainability of housing stock of Belgrade, as an energy system, is based on three aspects (energy indicators): economic, environmental and social [Afgan, N.H. and Carvalho, M.G. 2000]. As a measure of evaluating the contribution of different factors in assessment of the energy system, three energy sub-indicators are defined for each energy indicator (Fig.8). Sub-indicators are selected to describe, in best way, the political and economical aspects of energy of the country, as well as the social status of citizens, and the quality of the environment.

In this paper, we analyzed nine selected sub-indicators (from a variety of them), in order to present the impact of selected sub-indicators and priority which is given to one of them, on the value of the total index of sustainability. Choosing sub-indicators and giving priority to some of them, depends on needs of users such as: state, region, municipality, etc....

Economy Indicator

The economy indicator is based on the elements including: energy unit cost sub-indicator (Ec1), heating load sub-indicator (Ec2) and efficiency sub-indicator (Ec3) (Tab.1).

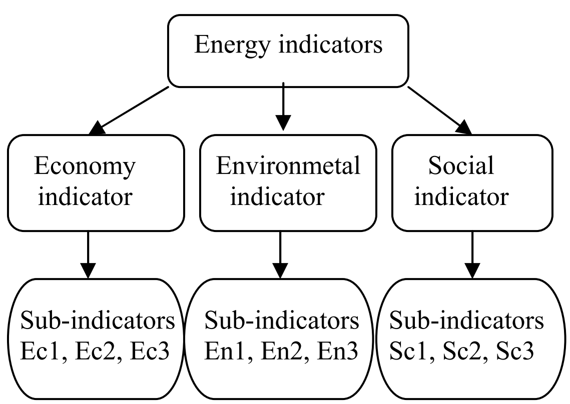

Figure 8. Scheme of energy indicators and sub-indicators for sustainability assessment of the Belgrade residential housing stock

Energy unit cost sub-indicator (Ec1) is the cost of energy per unit of produced energy. For all chosen objects for this analysis, Ec1 values are presented in Tab.4. There is only one Public Utility Company "Beogradske elektrane" in Belgrade supplying the city with thermal energy. For the object A, which is connected to the district heating system, Ec1 is a cost of 1kWh of thermal energy for residential building sector [Public Utility Company]. For the object B, Ec1 is calculated as a market price for the 1kg of LPG fuel divided by its calorific value. There is a specific tariff system for the electricity in the country. For the average private consumers of electricity (blue zone) there are different prices for day and night. Price for the night is almost four times lower then for the day [Company for the distribution]. The object C is supplied with heating appliances capable to accumulate heating energy during the night and to emit it during the day. The object D is supplied with coal stove burning domestique lignite. Value Ec1 for this object is obtained as a rate of domestique lignite cost and its calorific value.

If we assume that there is not a big difference between the outside temperatures of chosen objects in the same city and no big difference between inside temperatures, heating load sub-indicator (Ec2) (Tab.4) comprise the thermal quality of the object, the energy necessary for the object season heating per square meter of the heating surface area. For object A, this value is obtained from district heating company [Public Utility Company] for the selected building. All other Ec2 values (for objects B, C and D) are calculated as a total amount of heating energy for one heating season (got from the owners) divided by the heating surface area in square meters.

Efficiency sub-indicator (Ec3) (Tab.4) is defined as thermodynamic efficiency of the energy producing system. It is efficiency of conversion from the energy resources to the final energy. For the object A, connected for the district heating system using natural gas as a fuel, efficiency is 55% [Landberg, H. 2005.] For objects (B and D) efficiency is obtained from the producer manual for heating appliances. For the object C, which uses electrical energy for space heating, the adopted efficiency coefficient is about 38% [Jovanovic M. 2009, Ph.D. Thesis].

Environment Indicator

The environment indicator consists of three sub-indicators En1, En2 and En3 showing, respectively emitted amounts of CO_2, NO_x and SO_2 to the environment during production of a energy unit (Tab.2). In order to get 1kWh of energy by burning diferent fuel types (natural gas, LPG or lignite coal), those sub-indicators are calculated from coefficients given in a form "emitted amount of pollutant per unit of energy" [Energy development strategy of Republic of Montenegro]. All values for those sub-indicators are shown in Tab.4.

<u>Social Indicator</u>

The social indicator is based on three sub-indicators Sc1, Sc2 and Sc3 giving a social picture of introduced household (Tab.3). Sc1 shows percentage of household income spent on a living space heating. Sc2 is income per person in a household, and Sc3 is sub-indicator representing commodity of dwellers depended on "how much space per person is available in the object". All those values are given from the object owners and shown in Tab.4.

PROCEDURE FOR GENERAL INDEX SUSTAINABILITY DETERMINATION

To obtain the unique assessment quantity of various examined alternatives (object A, B, C and D) by multicriterial analysis methodology, ASPID method was used in this paper [Hovanov, N. 1996.]. The procedure is based on a list of initial values of 9 chosen sub-indicators from three different group of indicators and a list of 4 different options under investigation, as presented in Tab. 4. Those sub-indicators and options construct a matrix (x_i^j), i=1,…,m=9, j=1,…,k=4 where x_i^j is the value of i^{th} indicator for j^{th} option. The first level of calculation is to normalize all sub-indicators. Normalization consists of determination of membership functions $q_i^j(x_i^j)$, i=1,…,m=9, j=1,…,k=4. For every indicator x_i is necessary to fix Min (x_i^j for i=const. and j=1,…,k) and Max (x_i^j for i=const. and j=1,…,k) from all 4 initial values. In this paper linear normalization was adopted and membership functions are given in a form:

$$q_i^j = \begin{cases} 0, & x_i^j = \mathrm{Min}(x_i^j) \\ \dfrac{x_i^j - \mathrm{Min}(x_i^j)}{\mathrm{Max}(x_i^j) - \mathrm{Min}(x_i^j)}, & \mathrm{Min}(x_i^j) \langle x_i^j \langle \mathrm{Max}(x_i^j) \\ 1, & x_i^j = \mathrm{Max}(x_i^j) \end{cases} \qquad (1)$$

for every i=a, 1≤a≤m and j=1,…,k.

The second level of sustainability determination is to agglomerate specific criteria (normalized sub-indicator values) in one value for each indicator group: economical, environmental and social for each object. Agglomerated values are obtained by using linear agglomeration function:

$$Q(q,w) = \sum_i q_i w_i \qquad (2)$$

Table 1. Economy sub-indicators

Sub-indicator	Name	Definition	Unit
Ec1	Energy unit cost sub-indicator	Energy unit cost indicator is the cost of the energy per unit of produced energy.	€/kWh
Ec2	Heating load indicator	Necessary amount of energy for the one year long heating divided by heating surface area in square meters.	kWh/m^2
Ec3	Efficiency indicator	Efficiency of conversion from the energy resources to the final energy.	%

Table 2. Environment sub-indicators

Sub-indicator	Name	Definition	Unit
En1	Carbon-dioxide environment sub-indicator	The amount of carbon dioxide emitted in the environment per kWh of produced energy	kg/kWh
En2	Nitrogen -oxide environment sub-indicator	The amount of nitrogen oxide emitted in the environment per kWh of produced energy	kg/kWh
En3	Sulfur-dioxide environment sub-indicator	The amount of sulfur dioxide emitted in the environment per kWh of produced energy	kg/kWh

Table 3. Social sub-indicators

Sub-indicator	Name	Definition	Unit
Sc1	Heating share sub-indicator	Share of household income spent on energy for heating.	%
Sc2	Household members' average income sub-indicator	Total income of household divided by number of households' member.	€/person
Sc3	Commodity sub-indicator	Living space in square meters per household members.	m^2/person

Table 4. Values of sub-indicators for selected object

Energy indicators	Economy			Environmental			Social		
	Ec_1	Ec_2	Ec_3	En_1	En_2	En_3	Sc_1	Sc_2	Sc_3
Object A	3.34E-2	124	55	0.201	0	1.66E-4	3.27	393.33	20
Object B	6.51E-2	69.1	90	0.225	0	2.48E-4	2.18	292.50	17
Object C	1.66E-2	118.5	38	0.357	5.838E-3	3.60E-4	1	335.00	20
Object D	3.63E-2	92.4	70	0.357	5.838E-3	3.60E-4	2.35	237.50	20

In this paper the priority is (by weighting factor w) on the first of three sub-indicators from each indicator group and for each object under consideration. The weighting factors are normalized in a way that their sum is always equal to 1.

At the third level of calculation, General Index of Sustainability is determined as an additive function based on agglomerated values of economic, environmental and social indicators for each object and weighting coefficients in the condition on predefined constraints.

ANALYSIS OF RESULTS

Application of multi-criterial methodology enables to choose the best option in terms of sustainability. Three different cases are presented in this paper (Case 1, Case 2 and Case 3). All those cases are made under constraints giving priority to one of the energy indicators by specific weighting factor.

Case 1 is designed by giving priority to the economy indicator among environmental and social by weighting factors (w(Ec)>w(En), w(En)=w(Sc)) as it shown at Fig.9. In the agglomeration process of sub-indicators, priority is given in a way w(Ec1)>w(Ec2)=w(Ec3), w(En1)>w(En2)=w(En3), w(Sc1)>w(Sc2)=w(Sc3). In this case, when the economy indicator has priority, it can be seen from the Fig.10 that (even with relatively big standard deviation) the most sustainable option is object B. Object C is the worst one, and objects A and D have middle sustainability.

Case 2 is designed by giving priority to the environmental indicator among economy and social by weighting factors (w(En)>w(Ec), w(Ec)=w(Sc)) as it shown at Fig.11. In the agglomeration process of sub-indicators, priority is given in a way w(Ec1)>w(Ec2)=w(Ec3), w(En1)>w(En2)=w(En3), w(Sc1)>w(Sc2)=w(Sc3). In this case, when the environmental indicator has priority, it can be seen from the Fig.12 that the most sustainable option is object D. Taking account standard deviations of General Sustainability Index of objects D and C, even C option is good enough. It is obvious that object C has very bad sustainability if priority is on the economy aspect and very good sustainability if priority is on the environmental aspect.

Case 3 is designed by giving priority to the social indicator among economy and environmental by weighting factors (w(Sc)>w(Ec), w(Ec)=w(En)) as it shown at Fig.13. In the agglomeration process of sub-indicators, priority is given in a way w(Ec1)>w(Ec2)=w(Ec3), w(En1)>w(En2)=w(En3), w(Sc1)>w(Sc2)=w(Sc3). In this case, when the social indicator has priority, it can be seen from the Fig.14 that (even with relatively big standard deviation) the most sustainable option is object A. It is obvious that object A has very bad sustainability if priority is given to the environmental aspect and middle sustainability if priority is given to the economy aspect.

CONCLUSION

Nowadays, cities are the biggest consumers of different kind of energy. This paper presents an attempt to define group of indicators for the sustainability assessment of residential building energy system in Belgrade, regarding three main energy indicators: economic, environmental and social.

For each group of energy indicators, a set of three sub-indicators are defined: energy unit cost, heating load and efficiency sub-indicators as the consisting elements of economic indicator. Also, attention is focused on the environment aspect of the building including CO_2, SO_2 and NO_x environmental sub-indicators as the consisting elements of environmental indicator. Special attention was devoted to the social indicator consisting of: heating share sub-indicator, family income per member of household and commodity sub-indicator.

Methods, which have been previously used for making decisions related with future development of energy systems, considered only economic parameters. Multicriteria analysis, in addition to economic, takes account environmental and social sub-indicators in calculating the total index of sustainability.

Presented method includes mutual relationship of all weighting factors taken account. Priority is given to the criteria by weighting factor and should depend on an expert opinion. Three different cases are presented using the constraints as a non-numerical information. Those cases are analyzed to show the influence of indicators, sub-indicators and constraints on the choice of the most sustainable alternative.

The goal, that remains for the future work, is to choose more sub-indicators and more objects in order to obtain more accurate values of the total index of sustainability.

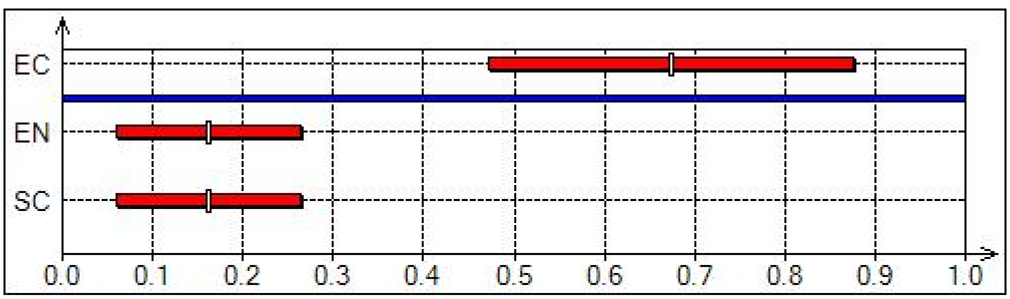

Figure 9. Weighting factors for Case 1

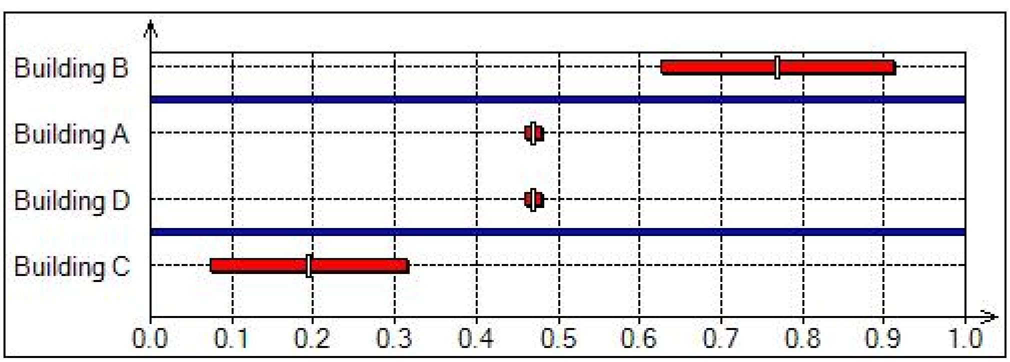

Figure 10. General Index of Sustainability for Case1

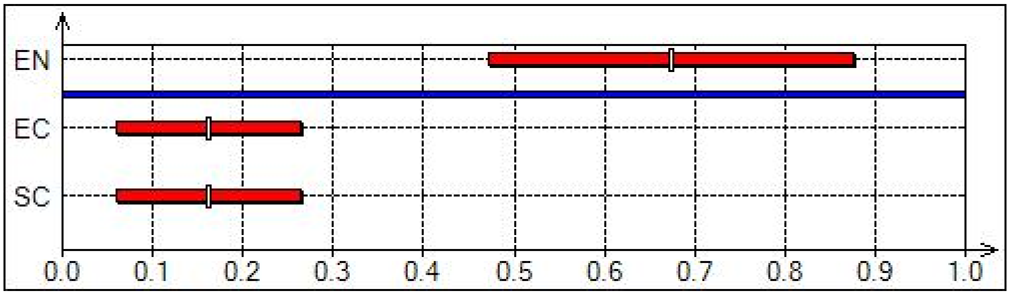

Figure 11. Weighting factors for Case 2

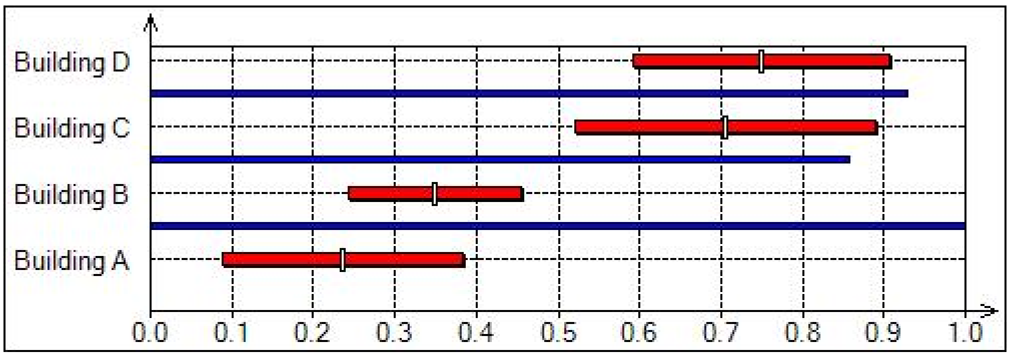

Figure 12. General Index of Sustainability for Case2

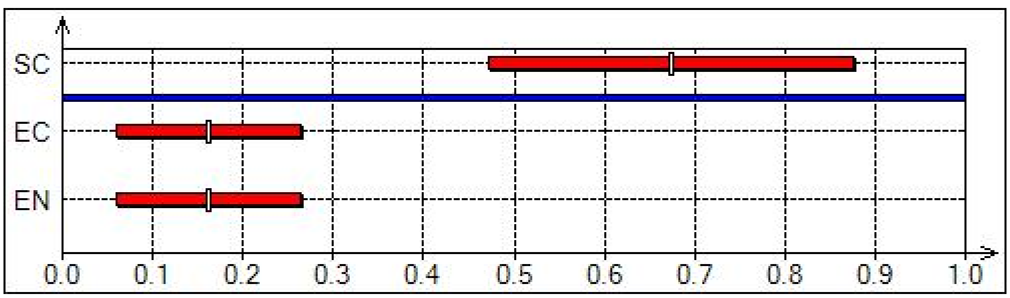

Figure 13. Weighting factors for Case 3

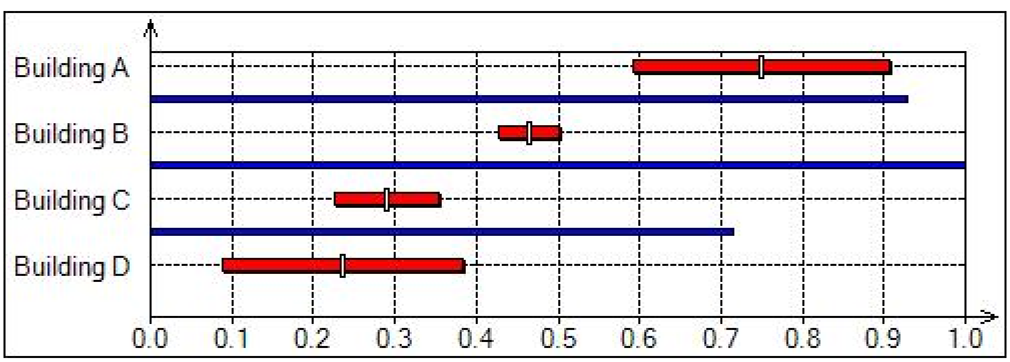

Figure 14. General Index of Sustainability for Case 3

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