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MULTIPLE CRITERIA EVALUATION OF BUILDINGS WITH EMPHASIS ON SUSTAINABILITY

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Abstract. It this article the author discussed how buildings influence environment. The main sustainable buildings information sources' review was made briefly. There are guides, handbooks, guidelines, databases, software and web-based tools. This information is needed to facilitate decision-making during the completion of a building's design, its construction and at the operational stages. Also, retrieval of the existing building rating systems was performed. Obstacles were clarified for the usage of the rating systems. The MCDM-23 (multi-criteria decision-making method) as a building's rating system was chosen, copied from Internet an installed into a personal computer. This program automates a multi-criteria evaluation. This paper/research performed an evaluation and comparison of two single-family house projects "Kedras" and "Vasaris". It is found that the project "Kedras" is better than "Vasaris".

Keywords: sustainable buildings, buildings rating systems, multi-criteria evaluation, comparison.

1. Introduction

The construction and use of buildings makes negative influence on urban and the whole environment. Tall buildings can produce dangerous winds in the neighbourhood, many buildings suffer from "sick building" syndrome. It is estimated that buildings in EU consume about 40 % of total energy, they generate about 30 % of total CO_2 emission and generate about 40 % of total technological waste. There is an increasing trend to build so-called sustainable buildings. One can get buildings' sustainability in different stages: by thoroughly selecting building products and materials, by selecting the best building's design scheme from several alternatives, by using the most suitable construction technology, etc.

2. Major information sources related to sustainable building materials and sustainable buildings design

According to information character and complexity information sources can be grouped as follows: elementary rules, guides, handbooks, guidelines, databases, software, web-based tools and rating systems.

Very often a decision maker can make decisions using elementary rules [1].

Guides, handbooks and guidelines. There are "Green Building Resource Guide" [2], "Building Materials for the Environmentally Hypersensitive" [3], "Sustainable Energy Guide" [4], "Energy Efficiency and Renewable Energy" [5], "Sustainable Building Sourcebook" [6], "Eco-Design" books available [7], etc.

Databases. There are "Oikos" [8], 'Green Building Products and Materials" databases available [9], etc.

Software. Much software has been developed to facilitate solving energy consumption problems in buildings. There are "Solar-5.7" [10], "HEED" [10], "Climate Consultant" [10], "Solar-2"[10], "Opaque" [10], "Enerpass" [11], "PowerDOE" [12], and "Energy-10" available today [13]. More software can be found by entering these keywords into computer search engine: "Energy performance of buildings", "Energy simulation tools" and "Energy performance tools", etc.

Web-based tools. These tools provide particular information to the user. For example, "Urban options" [14] provides information about energy, water, materials and money saving; and in reducing the environmental burden. In "Home Energy Saver" [15] an energy audit of one's own house can be performed. This tool provides ways of how energy consumption can be reduced and also offers house fixture alternatives.

3. Buildings rating systems

Further review of most popular buildings rating systems is presented.

GBTool. Canada

A hierarchical system of assessment criteria for buildings, developed for the purpose of analysing buildings. Three basic versions exist: multiunit residential buildings, office buildings and schools. The system comprises of six sections and 19 categories of assessment. A total of 100-150 individual assessment criteria are implemented. Evaluation focuses on assessing the environmental quality of buildings during design or after completion. Primary spatial unit of assessment is the building including to some extent the site. From the market point of view the system could serve as a basis for an environmental labelling/certification system for buildings [16].

LEED (Leadership in Energy and Environmental Design). USA

This is voluntary, consensus-based, market-driven building rating system based on existing proven technology. It evaluates environmental performance from a "whole building" over a building's life cycle. It is designed for rating both new and existing commercial, institutional and high-rise residential buildings. Within the system, points or credits are earned for satisfying each criteria and based on the evaluation, different levels of green building certification are awarded. Users: building design, construction industry and/or building business professionals or facilities staff or executives [17].

BREEAM (Building Research Establishment Environmental Assessment Method). UK

This method provides authoritative guidance on ways of minimising the adverse effects of buildings on the local and global environments. The assessment is based on "credits" awarded for a set of performance criteria. The assessment outcome is a certificate or label that enables owners or occupants to gain recognition for their building's environmental performance. Thus the assessment is aimed at meeting clients (owners, developers and occupiers) environmental assessment needs. Environmental performance is assessed under nine main categories. The system is modularised to facilitate assessment of new and refurbished buildings, existing and occupied building. Both quantitative and qualitative data are considered in parallel in the assessment process [18].

LCA-HOUSE. Finland

The tool, LCA-House was developed for environmental impact evaluation and for comparing or benchmarking buildings and different structure solutions. The result of the program is the plot of five environmental characteristics: two for energy use and three for describing emissions. These characteristics are the same as used in the building material environmental declaration: renewable energy, non-renewable energy, climate change potential, acidification potential and photochemical oxidant potentials. This tool can be used by researchers, designers, constructors, owners and material producers [19].

BEAT 2000 (Building Environmental Assessment Tool). Denmark

This tool is a PC program for performing life cycle based environmental assessment of buildings and building elements. It is developed at the Danish Building Research Institute (SBI) and consists of a database for systematic storing all quantifiable environmental data and an inventory tool for calculating the potential environmental effects for buildings and building elements. The database contains data for most common energy sources, means of transport, building materials and building elements used in the Danish building sector [20].

LCA-Tool. Finland

This tool is integrated LCA-tool which uses a database containing data on building constructions and technical systems. The unique integrated software tools and the database including data of systems, equipment and material make it possible to use the LCA-tool for calculating the environmental impacts at different stages of the design as well as the whole life cycle of the building. The LCA-tool prints out the environmental profile of the building and this profile shows clearly which alternative building parts or systems produce the most significant environmental loads. The profile is a useful help for the building owner in decision making at different stages of the building life cycle and also in steering the design and construction process towards ecological and sustainable solutions [21].

EQUER. France

Equer, developed by a team led by Ecole des Mines de Paris, is an LCA oriented tool. It contains product data bases of Swiss and German origin. It is coupled with a energy analysis software, Comfie. Equer calculates 12 environmental indicators. Outputs are presented by an eco-profile, with the possibility to display the contribution of each phase of the building life cycle, and to compare variants [22].

ESCALE. France

Escale, developed by CSTB and University of Savoie, is a method able to assess the environmental quality of a building along its design phases. 11 main criteria have been defined, representing, for instance, impacts on outdoor environment at different geographic scales, users' comfort and health, environmental management. Two levels of models exist, simplified and detailed, in order to square with the availability and accuracy of data. The final profile is expressed in terms of performance scores, complemented by explanatory sub-profiles [22].

PAPOOSE. France

Papoose, developed by TRIBU, is defined as a decision-aid tool, targeted to building owners. It covers various design stages by different calculation levels. It deals with a dozen of environmental themes, with a particular attention to energy and to the users, and include cost aspects. Results are presented in numerical and graphical form, given among other things performances expressed in percentage [22].

TEAM. France

Team for Buildings, developed by Ecobilan, is a variant of the TEAM LCA software, adapted to the building sector. It includes the DEAM database covering numerous industrial fields. It enables the user to model graphically complex systems thanks to the nesting of systems and sub-systems. The user has the choice between different methods to translate flow inventories into impact indicators [22].

MCDM-23. USA

The National Renewable Energy Laboratory in the USA developed MCDM-23. This program automates multi-criteria analysis. As a result, MCDM-23 produces worksheets, bar charts and star diagrams. The program as a default can assess a life cycle's cost, use of resources, environmental loading, indoor climate, functionality and architectural expressions. The user is allowed to change one criterion with another. The program is able to perform computation both with quantitative and qualitative criteria. The method proposed consists of six steps that are as follows: the first three steps are carried out in the first phase, the last three steps are carried out in the second phase, after generating the schemes and when making the decisions. The first phase: selecting the main design criteria and sub-criteria; developing measurement scales for the sub-criteria; weight the main criteria and sub-criteria. The second phase (generates alternatives): predicts performance; aggregates scores; analyses results and makes decisions. The results of these computations can be easily interpreted by anyone: eg an architect, engineer, client, real estate developer and building official, etc. The winner will be that project scheme which collects the most points/scores [23].

EcoEffect. Sweden

EcoEffect is a method for environmental assessment of buildings including the outdoor environment. It is developed for existing multi-residential buildings. The structure is general and the method is being adapted to the assessment of planned buildings. The results of the assessment are presented in four environmental profiles. Energy use and materials use represent external effects, indoor and outdoor environment represent internal effects [24].

Eco-Quantum. The Netherlands

Eco-Quantum is an LCA based computer based tool which calculates the environmental effects during the entire life cycle of the building from the moment the raw materials are extracted, via production, building and use, to the final demolition or reuse. Two versions of Eco-Quantum are available. Eco-Quantum Research is a tool for analysing and developing innovative and complex designs for sustainable buildings and offices. Eco-Quantum Domestic is a tool which architects can apply to quickly reveal environmental consequences of material and energy use of their designs of domestic buildings. The architect can environmentally optimise the design in various ways. The components and constructions which offer the largest environmental benefit are indicated [18].

GreenCalc. The Netherlands

GreenCalc method calculates what it would cost to prevent the environmental damage of buildings construction and use. It also makes use of the life cycle assessment methodology, but does not restrict to this. GreenCalc introduces the TWIN concept, which combines available quantitative data with estimated qualitative data. Furthermore, it is not limited to energy, materials and water, but it also takes mobility aspects into account. Finally, it does not express the results in environmental effects, but in environmental costs. GreenCalc is mostly used for office buildings [25, 26, 27].

EcoProp. Finland

Evaluation focuses on assessing the environmental quality of buildings during design, during construction or at the delivery. The emphasis is at the early stages of the design process. Primary spatial unit of assessment is the building, to some extent including the site. Some criteria refer to the public transport system and other services of the surrounding community, however these are also taken into account from the viewpoint of the individual building. The system is primarily addressed to clients (owners, developers) to the early phases of development and design of buildings. It can well be applied by other actors and also in other phases of the process [28].

BEES (Building for Environmental and Economic Sustainability). USA

BEES is an interactive computer design aid that helps users select building products for use in commercial office and housing projects in a way that balances environmental and economic criteria. A range of material options can be compared for different elements of the building, using graphical outputs of a range of environmental and economic criteria, considered individually or in combination. The environmental performance measure is derived using the ISO 14000 standard life cycle assessment approach and covers six impacts – resource depletion, global warming, acidification, eutrophication, indoor air quality and solid waste. Economic performance is derived using the ASTM standard life-cycle costing approach and includes the cost of purchase, installation, maintenance, repair, replacement, and disposal over 50-years use stage. Environmental and economic performance are combined using the ASTM standard for multi-attribute decision analysis [18].

BRE Environmental Profiles. UK

Environmental Profiles are a method of gathering and presenting environmental data to compare the environmental performance of building materials. They enable architects, specifiers and clients to make informed decisions about construction materials and components, by providing a method for independent, "level playing field" information about the relative environmental impacts of different design options. Profiles may be calculated for materials, components and building elements. The building elements Profiles can be presented as "built" or over a nominal life. The method is relevant to design, construction and operation activities. It also includes issues for material manufacturers for product stewardship and building lifecycle [18].

OSLAT (Office, Schools and Local Authority Toolkits). UK

The Toolkits are designed to help facilities, building or office managers to improve the environmental performance of their buildings, and indicate where these activities will help them save money. It is possible to use the toolkits in their own right or as a stepping stone towards a formal accreditation system, such as EMAS or ISO 14001. The Toolkits examine and evaluate the building based aspects which might have an environmental impact, with the exception of manufacturing. It looks not only at direct impacts such as energy, water and waste, but also at indirect issues such as commuting and business travel. In all it considers 17 different aspects [18].

ENVEST. UK

ENVESTis the first UK software tool for estimating the life cycle environmental impacts of a building from the early design stage. The first version is for office buildings and considers the environmental impacts. Data is provided by the tool. Information about the size, fabric and service options for the proposed building is entered through input screens. ENVEST allows designers to instantly identify those aspects of the building which have the greatest influence on the overall impact. All environmental impacts are measured using a simple points scale called Ecopoints allowing the designer to compare different designs and specifications directly. 100 Ecopoints are equivalent to the environmental impact of the average UK citizen in 1 year [18].

ATHENA. Canada

The Athena lets for architects, engineers and researchers assess the environmental implications of industrial, institutional, office, and both multi-unit and single-family residential designs. Where relevant, it is also distinguishes between owner-occupied and rental facilities. Results from an individual design can be seen in summary tables and graphs by assembly group and life cycle stage. Detailed tables and graphs show individual energy use by type or form of energy and emissions by individual substance for both the assembly group and life cycle stage breakouts [29].

LISA. Australia

LISA (Life Cycle Analysis (LCA) in Sustainable Architecture) is streamlined LCA decision support tool for construction. It was developed in response to requests by simplified LCA tool to assist in green design. LISA provides preformatted reports, user definable, in graphical and table form showing the environmental impact. Audience: architects, construction industry professionals, educators, researchers [30].

EcoPro. Germany

EcoPro is a Life Cycle Analysis (LCA) tool. It calculates the impacts of energy and material usages and flows on the environment. It allows modelling life cycles of products in graphical flow-chart manner. The life cycle systems can contain as many subsystems as you like, a top-down approach is possible. Ecopro can be used by architects during: preplanning, preliminary design and definite design [30].

Ecoprofile. Norway

Ecoprofile is a top down method for environmental assessment of existing office buildings. It consists of three main areas: outdoor environment, use of resources and indoor environment focussing on energy flexibility and efficiency use of hazardous materials. Each of the main areas has 4–6 sub-areas with a total of approximately 90 parameters assessed within these areas. Each sub-area is weighted. The method is based on the use of standardised schemes, questionnaires and reports to minimise the work of assessment and this makes it is easy and cheap to use. Quantitative and qualitative data is used [18].

PIMWAQ. Finland

PIMWAQ is a method which defines minimum ecological levels for residential building and asesses the ecological degree of various development projects. Evaluation focuses on assessing the environmental quality of buildings during design or after completion. Primary spatial unit of assessment is the building, to some extent including the site. End users will be owners, building developers to set requirements and authorities to append to regulations, and designers to test their plans [31].

The review of buildings rating systems shows that they are designed in particular countries and that they have databases that are related to those countries. Consequently, it is difficult to apply these rating systems to other countries. Another problem is that well-established rating systems require special knowledge and training in their usage. A third aspect is that most rating systems are not free of charge.

With the buildings rating systems one can perform not only one building design scheme's assessment but can also do a comparable analysis of several building designs from various aspects. For further tests MCDM-23 (a Multi-criteria Decision Making Tool for Buildings) program has been chosen. One can find this program on the Internet, download it into one's own computer and use it absolutely free. It is worth to notice that team of Lithuanian and German scientists [32] developed program LEVI 3.0 which is able to perform comprehensive multi-criteria evaluation.

4. Evaluation and comparison of two buildings

Short project's description. For an evaluation of two single-family house project schemes "Kedras" and "Vasaris" were selected. Their living area is almost equal and has accordingly, 145 m^2 and 143 m^2. 'Kedras' has wooden framework and a natural gas heating system. It is a single-storey, good-sized, comfortable and warm house that meets the state-of-the-art requirements. It also has large windows so by having natural- daylight the house is fulfilled. 'Vasaris" is a more traditional and conservative project. It is a single-storey house with cockloft and basement. The main structure has been designed from masonry. The heating system uses firewood. The price of both projects consists of the cost of materials and construction works.

Criteria system that characterises the projects

Criteria	Sub-criteria	Values	
		"Kedras"	"Vasaris"
1. Life cycle's cost	1.1. Construction cost	338 770 Lt	336 600 Lt
	1.2. Annual maintenance cost	480 Lt	360 Lt
2. Resource uses	2.1. Annual electricity	1700 kWh	1500 kWh
	2.2. Annual fuels	9 points	8 points
	2.3. Annual water	145 m^3	130 m^3
3. Indoor climate	3.1. Air quality	9 points	7 points
	3.2. Daylight	10 points	6 points
	3.3. Thermal comfort	8 points	7 points
4. Functionality	4.1. Functionality	9 points	7 points
	4.2. Flexibility	9 points	8 points
5. Architectural expression	5.1. Scale/proportion	8 points	9 points
	5.2. Integrity/coherence	8 points	8 points

Main criteria, sub-criteria and values.

1.1. **Construction cost** depends on the sort of materials and the quantity of materials and also on the structures that were used on the construction's technology, and on some other factors such as heating, ventilation systems, etc. 1.2. **Annual maintenance cost** assesses costs that are needed to maintain the building in good condition. 2.1.**Annual electricity**, 2.2. **Annual fuels** and 2.3. **Annual water** describes the consumption of the main resources that are needed for the building's operation and by the occupants. 3.1. **Air quality** assesses the materials used from an ecological viewpoint. 3.2. **Daylight** depends on the house's windows quantity and size. 3.3. **Thermal comfort** is assessed according to how much effort was needed to control and maintain the heating process. 4.1. **Functionality** describes comfort and layout of the rooms. 4.2. **Flexibility** describes the possibility of transforming the house's space. 5.1. **Scale/proportion** assess the proportion of the building and rooms' spaces. 5.2. **Integrity/coherence**. Here the aesthetical view was assessed (Table).

Measurement scales for the sub-criteria. **1.1. Construction cost, Lt:** 220.000 – 10 points (excellent); 260.000 – 9 points (good to excellent); 300.000 – 8 points (good); 340.000 – 7 points (fair to good); 380.000 – 6 points (fair); 420.000 – 5 points (acceptable to fair); 460.000 – 4 points (marginally acceptable). **1.2. Annual maintenance cost, Lt:** 200 – 10 points; 300 – 9 points; 400 – 8 points; 500 – 7 points; 600 – 6 points; 700 – 5 points; 800 – 4 points. **2.1. Annual electricity, kWh:** 1.200 – 10 points; 1.600 – 9 points; 2.000 – 8 points; 2.400 – 7 points; 2.900 – 6 points; 3.400 – 5 points; 4.000 – 4 points. **2.3. Annual water, m^3:** 120 – 10 points; 125 – 9 points; 130 – 8 points; 140 – 7 points; 150 – 6 points; 160 – 5 points; 180 – 4 points.

5. Results of the evaluation and comparison

After computation by using the MCDM-23 program, one obtained the following results: weighting for the main criteria (Fig 1); bar charts for excellent results, marginally acceptable, "Kedras" and 'Vasaris" (Fig 2); star diagram of the "Kedras" project (Fig 3); star diagram of the "Vasaris" project (Fig 4).

The weights of criteria was set by decision maker using the so-called grading method. It works as follows:

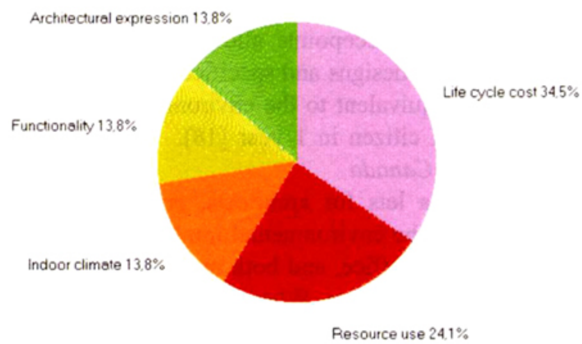

Fig 1. Weights of the main criteria

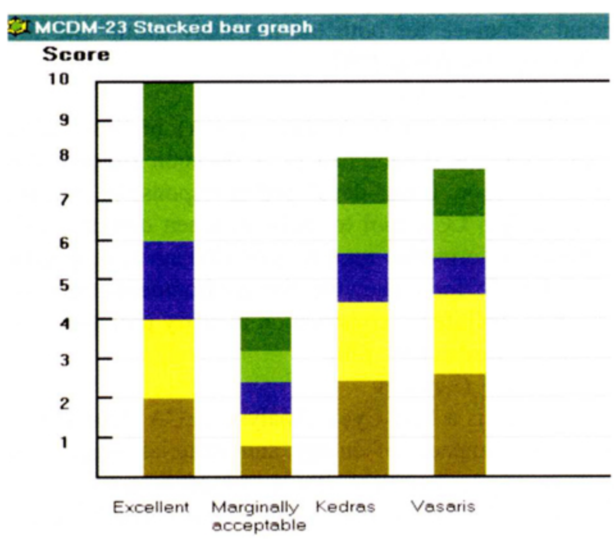

Fig 2. Bar charts of excellence and the marginally acceptable for the "Kedras"and "Vasaris" project

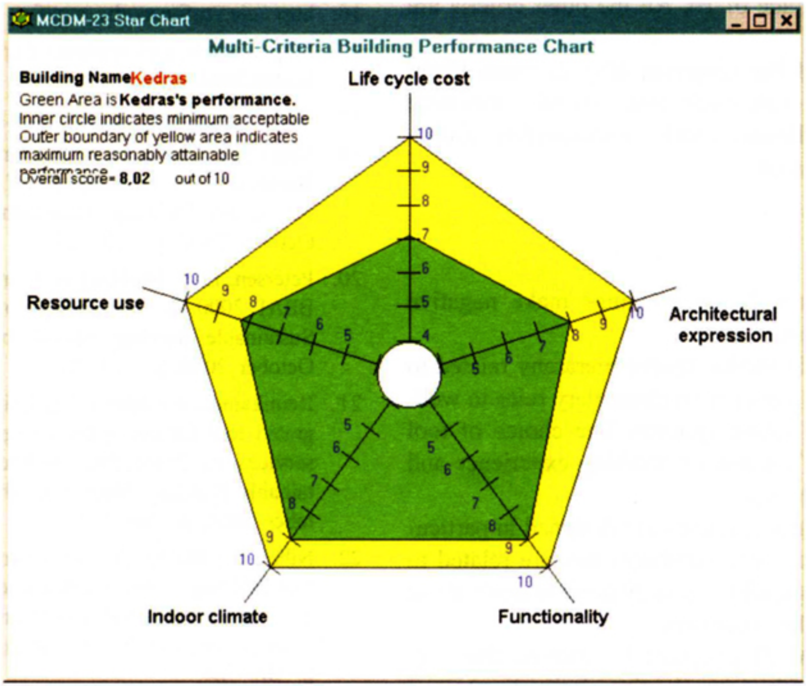

Fig 3. Star diagram of the "Kedras" project

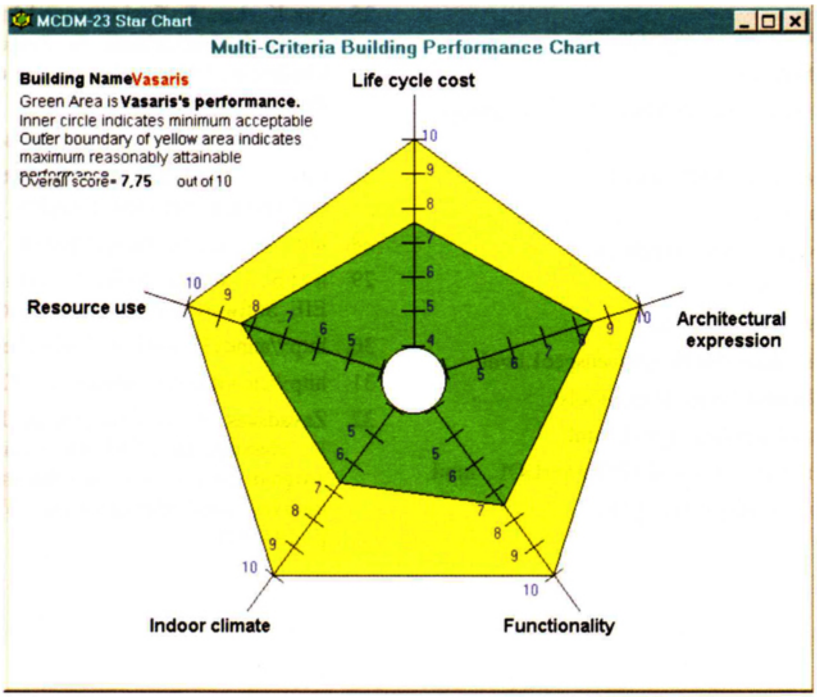

Fig 4. Star diagram of the "Vasaris" project

the decision maker expresses the importance of criteria in grades on the scale 10, 9, 8,...4. The most important criterion rceives a grade of 10. All the other criteria are compared to this.

The sections of bar diagrams (Fig 2) mean (from top to down): first – Life cycle cost; second – Resource use; third – Indoor climate; fourth – Functionality; sixth – Architectural expression.

6. Conclusions

1. It is recognised that buildings make negative effect on environment;

2. Existing information source hierarchy related to sustainable buildings varies from elementary rules to well-established building rating systems. The choice of tool depends on the user's demands, working experience and financial possibilities, etc;

3. Buildings rating systems are designed in particular countries and they have databases that are related to those countries, consequently, it is difficult to apply these rating systems to other countries;

4. The MCDM-23 program is selected that will automate the multi-criteria evaluation. It is easy to use this program and to check and interpret results by using it;

5. This program made an evaluation and comparison of the projects "Kedras" and "Vasaris" and it found that the project "Kedras" is better than "Vasaris".

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