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INTEGRATED MODEL AND SYSTEM FOR PASSIVE HOUSES MULTIPLE CRITERIA ANALYSIS

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ABSTRACT. In order to design and implement a high-quality passive house project, it is necessary to take care of its efficiency from the brief stage to the end of its life's service. The entire process should be planned and executed with a consideration of the goals that are aspired to by the participating and interested parties and the micro, meso and macro environment levels. In order to realize the above purposes, an original Model for an Integrated Analysis of Passive Houses and Passive Houses Design Multiple Criteria Decision Support System was developed by the authors, enabling one to analyze a passive house's life cycle, the parties involved in the project and its micro, meso and macro environment as one integrated entity.

KEYWORDS: Passive house; Energy efficiency; Multiple criteria analysis; Integrated model; Decision Support System

1. INTRODUCTION

Considering the tendencies of energy production and price, it is becoming urgent to reduce energy consumption in buildings (Venckus et al., 2010). In 1997, the developed nations agreed in the Kyoto Protocol to limit their greenhouse gas emissions. The residential sector accounts for a significant part of the final energy consumption in the European Community and, therefore, the built environment is an important target of the governmental environmental policies resulting from the Kyoto Protocol (Smid and Nieboer, 2008). In January 2007 European Commission encouraged 27 EU states to set a goal and by 2020 reduce exhaust gases contributing to the greenhouse effect by 30% in mature countries and at least by 20% in the European Union. Later in Brussels it was agreed upon certain legally obligatory objectives, among them reduction of exhaust gases contributing to the greenhouse effect at least by 20% and production of 20% of energy from regenerative resources. The EU already endeavours to achieve the objectives raised in its respect by Kyoto Protocol, therefore the areas suffering from the impact on the environment – transportation and power economy of these – are challenged a lot (Transportas ir energetika, 2008). Energy efficiency is an essential element in making efforts to ensure 20% reduction of primary power consumption by 2020. If this aim is attained general EU energy consumption would decrease by 13%, approximately 100 billion euro and 780 billion tones of CO_2 would be saved yearly. The European Commission suggested programmes designed to boost the efficiency of household devices, improve heat and electricity production and develop energy parameters in buildings and international agreement on energy efficiency. However, the highest energy efficiency potential lies in building construction and operation methods. Presently buildings absorb 40% of EU consumed energy (Transportas ir energetika, 2008). It has been established that the fifth part of currently consumed energy could have been saved. Everybody agrees that the potential of energy saving in buildings is huge (Monstvilas et al., 2010; Huang and Hsueh, 2010; Motuziene and Juodis, 2010).

The most comprehensive and widely used concept of a very low energy in Europe is offered by the German scientist Feist (Passive House Institute, 2010), also called the passive house concept, where the maximum permissible energy consumption for the heating of the building are presented, and at the same time, the total primary energy consumption is limited. A passive house is a cost-efficient building that can manage throughout the heating period, due to its specific construction design, with more than ten times less heat energy than the same building designed to standards presently applicable across Europe (Badescu et al., 2011). The requirements for building elements thermal properties and the air tightness of the building are also presented in this concept (Venckus et al., 2010). Lithuania is also foreseeing the design and construction of passive houses.

2. LITERATURE REVIEW

Theoretical and practical aspects of passive house life cycle and its environment were dealt with in various research papers and projects. For example, Osmani and O'Reilly (2009) research found that there are currently numerous legislative, cultural, financial and technical barriers facing house builders to deliver zero carbon homes in England by 2016.

The target of the Austrian research project "Lehm Konkret" was to develop a sustainable building solution that takes all three dimensions of sustainability into account. Besides environmental aspects such as the recyclability, energy efficiency in production and use phase of the building, aspects of social sustainability like health and comfort as well as the achievability of the building solution have been considered. By joining forces, partners of industry, science and building practice developed a solution for the Passive House Standard based on unfired, industrially produced and ecologically optimized loam bricks (Vieira and Macho, 2009).

Schnieders and Hermelink (2006) presented detailed measurements for 11 "Passive House" projects with more than 100 dwelling units from the EU-funded demonstration project CEPHEUS (Cost Efficient Passive Houses as EUropean Standards). All projects exhibited extraordinarily low space heat consumptions. Compared with ordinary, newly erected buildings, 80% of the space heat consumption could be saved. The total primary energy consumption (including household electricity) was less than 50% of that of conventional new buildings. The measurements showed that the buildings also offered comfortable indoor conditions in both summer and winter. Authors concluded that this building type fulfils the conditions of sustainability in social, ecological and economic respects and should herefore be disseminated on a larger scale.

Mahdavi and Doppelbauer (2010) compared apartments in two residential blocks in Vienna; one passive and the other one low-energy. These blocks were constructed simultaneously in the same location and with comparable building construction features and floor plans. Authors concluded that passive buildings – as compared to low-energy buildings – used significantly less heating energy and offered slightly better indoor conditions. Thereby, the required additional expenditure of resources (as represented by embodied energy) and environmental impact (as represented by CO_2 emissions) were offset in a rather short period. Moreover, the required addition construction cost does not appear to be either excessive or prohibitive.

In order to improve energy efficient construction must rest on an integrated analysis and rational decision-making at the micro, meso and macro levels. In addition to economic and legal/regulatory decisions, other aspects of political, social, culture, ethical, psychological, educational, environmental, provision, technological, technical, organizational and managerial, should be considered as well.

Recently, much attention has been paid to the issues of passive houses and passive house components reflecting in scientific models proposed by various researches, e.g. model for the ground heat exchanger (Badescu, 2007a), heating system (Badescu, 2007b), heating model of the active solar heating system (Badescu and Staicovici, 2006), earth-contact building structures (Kumar et al., 2007), a regression model of energy efficiency (Tzikopoulos et al., 2005), a computational fluid dynamics model (Karlsson and Moshfegh, 2006), etc.

Kumar et al. (2007) have derived new explicit analytical expression for earth-contact structures. A simple but effective mathematical model based on Fourier multi-variant input was used in this study to predict the variation of heat flux across the different earth-contact building structures and therefore to control indoor-air temperature. The model was validated with extensive sets of experimental data for New Delhi and very good agreement was found between the measured and predicted temperature values. This offers a much more useful analysis tool with nearly the same accuracy as a three-dimensional model.

Tzikopoulos et al. (2005) developed a regression model of energy efficiency as a function of environmental conditions, building characteristics and passive solar technologies. A sample of 77 bioclimatic buildings (including 45 houses) was collected, covering Greece, other Mediterranean areas and the rest of Europe. Average energy efficiency varied from 19.6 to 100% with an average of about 68%. Environmental conditions included latitude, altitude, ambient temperature, degree days and sun hours; building characteristics consisted in building area and volume. Passive solar technologies included (among others) solar water heaters, shading, natural ventilation, greenhouses and thermal storage walls. Degree days and a dummy variable indicating location in the Mediterranean area were the strongest predictors of energy efficiency while taller and leaner buildings tended to be more energy efficient. Surprisingly, many passive technologies did not appear to make a difference on energy efficiency while thermal storage walls in fact seemed to decrease energy efficiency. The model developed may be of use to architects, engineers and policy makers. Suggestions for further research include obtaining more building information, investigating the effect of passive solar technologies and gathering information on the usage of building.

In two companion papers Badescu and Sicre (2003a, 2003b) proposed a model to evaluate the contribution of renewable energy sources to meet the heating demand of a three-zone passive house. The three zones refer each to an area with quite similar indoor features (in terms of temperature and humidity), namely to: (1) the kitchen, (2) the bathroom and (3) the remaining rooms of the house. As a case study, the model was applied to the Pirmasens Passive House (Rhineland Palatinate, Germany). In this paper, authors presented a way of describing the structure of the passive house. The components and operation of the ventilation–heating system was also presented. The companion paper (Badescu and Sicre, 2003b) described the time-dependent models used to evaluate the thermal heat demand and the operation of the ventilation–heating system.

Yang et al. (2009) proposed and developed an updated two-region vertical U-tube GHE analytical model, which is fit for system dynamic simulation of GCHP. Model divided the heat transfer region of GHE into two parts at the boundary of borehole wall, and the two regions were coupled by the temperature of borehole wall. Both steady and transient heat transfer method were used to analyze the heat transfer process inside and outside borehole, respectively.

There are various passive houses and passive house components simulation tools developed by scientists and practitioners, e.g. dynamic simulation software (Thiers and Peuportier, 2008), computer-aided design tool for passive solar systems (Yakubu, 1996), simulation software for zero energy building design (Wang and Gwilliam, 2009), design of low energy buildings (Chlela et al., 2009), optimization tools BEopt and EGUSA (Parker, 2009), etc.

A computer-aided design tool for assisting the designer to set appropriate passive solar systems for heating and cooling is based on a knowledge base oriented design process (Yakubu, 1996). The knowledge base stores design guidelines and procedural methods for determining the passive systems that best suit the local climatic conditions. This tool is aimed to be used already at the very early stages of the design process, the pre-conceptual and the conceptual, with the purpose of achieving a passive solar architecture from the energy point of view that will better fit local climatic conditions. At the pre-conceptual design stage the system determined the bio-climatic strategies and at the conceptual design stage the recommended passive systems are presented according to previously selected design strategies. The design tool that was developed includes knowledge bases that contain examples and descriptive explanations. The knowledge base may be retrieved automatically by the system or upon request. Thus the system can support the designer as an expert that provides advice when needed (Yakubu, 1996). The model PASYS is based on various knowledge bases that give a wide support in the early stages of the design process. PASYS shows the designer a range of many possible solutions of the passive systems that fit the project in hand (Yakubu, 1996).

Wang and Gwilliam (2009) analysed possible solutions for zero energy building design in UK. Simulation software (EnergyPlus and TRNSYS 16) are employed in this study, where EnergyPlus simulations are applied to enable facade design studies considering building materials, window sizes and orientations and TRNSYS is used for the investigation of the feasibility of zero energy houses with renewable electricity, solar hot water system and energy efficient heating systems under Cardiff weather conditions. Various design methods are compared and optimal design strategies for typical homes and energy systems are provided.

The design of a low energy building requires parametric studies via simulation tools in order to optimize the design of the building envelope and HVAC systems. These studies are often complex and time consuming due to a large number of parameters to consider. Hence, Chlela et al. (2009) aimed to set up a methodology that simplifies parametrical studies during the design process of a low energy building. The methodology is based on the Design of Experiments (DOE) method which is a statistical method widely used in industry to perform parametric studies that reduces the required number of experiments.

According to Parker (2009), optimization tools such as BEopt and EGUSA, which characterize both renewable resource performance and that also of specific combinations of energy efficiency measures, will best guide designers to locate the most economically favorable mix to reach an energy neutral level.

Excellent results of thermal resistance and economical maintenance of a passive house are achieved using optimal architectural, construction and engineering solutions in an integrated manner. The application MagiCAD Comfort&Energy is especially useful for architects who design passive houses under international standards. Upon input of Lithuanian climatic data, this application calculates most key parameters of a passive house in a certain location. The specialised application bases its calculations on multi-annual meteorological indicators of entire Lithuania or even its separate regions. The application facilitates fast and precise simulation of energy needs and indoor comfort conditions (Mediniai namai, 2009).

Best practice databases and knowledge bases, as well as information, decision support, expert and knowledge systems, must be employed to make the use of passive houses in Lithuania more efficient. The Intelligent System for Multi-variant Design, Multiple Criteria Analysis and Selection of the Most Efficient Variants of Buildings developed by the authors could help to improve the efficiency of passive houses designed in Lithuania.

It is advisable to make better use of the explicit and tacit knowledge throughout the passive house lifecycle in Lithuania.

3. A MODEL FOR AN INTEGRATED ANALYSIS OF PASSIVE HOUSES

In order to design and realize a high-quality passive house project, it is necessary to take care of its efficiency from the brief stage to the end of its life's service. The entire process should be planned and executed with a consideration of the goals that are aspired to by the participating and interested parties and the micro, meso and macro environment levels. In order to realize the above purposes, an original Model for an Integrated Analysis of Passive Houses was developed by the authors, enabling one to analyze a passive house's life cycle, the parties involved in the project and its micro, meso and macro environment as one integrated entity. A Model for an Integrated Analysis of Passive Houses has been developed in the following stages:

Stage I. Comparative description of the passive house (economic, legal/regulatory, technical, technological, organizational, managerial, quality of life, thermical, indoor quality, social, cultural, political, ethical, psychological and educational factors) in developed countries and in Lithuania:

- A system of criteria characterizing the efficiency of passive house was determined by means of using relevant literature and experts methods;
- Based on a system of criteria, a description of the present state of passive house of developed countries and Lithuania is given in conceptual (textual, graphical, numerical, etc.) and quantitative forms.

Stage II. A comparison and contrast of passive house in developed countries and Lithuania:

- Identifying the global development trends (general regularities) of the passive house;
- Identifying passive house differences between developed countries and Lithuania;
- Determining pluses and minuses of these differences for Lithuania;

- Determining the best practice for passive house for Lithuania as based on the actual conditions;
- Estimating the deviation between stakeholders' knowledge of worldwide best practice and their practice-in-use.

Stage III. A development of some of the general recommendations as how to improve the knowledge levels for stakeholders.

Stage IV. Submission of particular recommendations for stakeholders were presented at this stage. Each of the general recommendations proposed in the fifth stage carry several particular alternatives.

Stage V. A multiple criteria analysis of passive house's components and a selection of the most efficient version of project's life cycle were determined at this stage. After this stage, the received compatible and rational components of a passive house are joined into the full passive house project.

Stage VI. Performance of transformational learning and redesigning the mental and practical behaviour:

- Stakeholders (firms) becoming aware and conceptualize of their practice-in-use;
- Stakeholders' (firms') becoming aware and conceptualize of their knowledge of worldwide best practice;
- Stakeholders (firms) estimating the deviation between knowledge of worldwide best practice and their practice-in-use;
- Performance of best practice learning;
- Fulfilling of best practice actions (understanding what the recurring motives caused manager' initial behaviour are; redesigning managers' core patterns of thought and behaviour);
- Performance of transformational learning (acquiring new manners of technological, social, ethical, etc. behaviour, get better understanding of how to interact with micro, meso and macro environment) and redesigning the behaviour.

4. A PASSIVE HOUSE DESIGN MULTIPLE CRITERIA DECISION SUPPORT SYSTEM

Based on the analysis of existing information, knowledge, expert and decision support systems and in order to determine most efficient versions of passive house the Passive Houses Design Multiple Criteria Decision Support (PHDMCDS) system consisting of a database, database management system, model-base, model-base management system and user interface was developed (Figure 1).

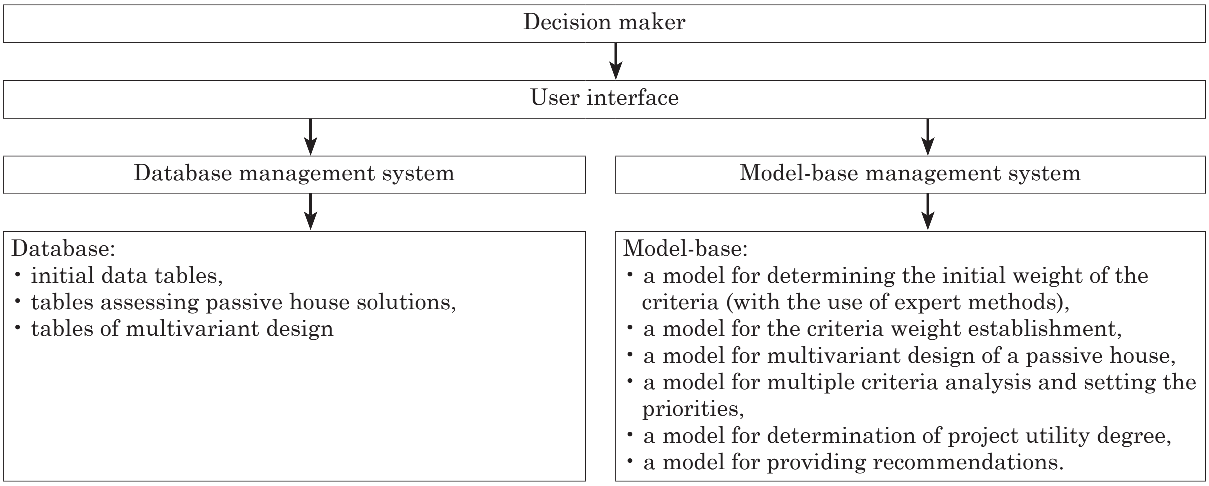

Figure 1. The components of PHDMCDS system

The PHDMCDS system was developed by using methods that were developed by Zavadskas and Kaklauskas (Zavadskas, 1987; Kaklauskas, 1999; Zavadskas and Kaklauskas, 1996; Zavadskas and Kaklauskas, 1999). These and other developed multiple criteria decision making methods were used by many authors for various tasks (Banaitienė et al., 2008; Kaklauskas et al., 2005; Kaklauskas et al., 2007; Kaklauskas et al., 2009; Kaklauskas et al., 2010; Ginevičius et al., 2008; Tupenaite et al., 2010; Zavadskas et al., 2009a, 2009b; Mickaityte et al., 2008; Kanapeckiene et al., 2010; Zavadskas et al., 2010a, 2010b, 2010c; Zavadskas and Turskis, 2010; Šliogerienė et al., 2009; Turskis et al., 2009; Urbanavičienė et al., 2009; Zavadskas et al., 2011; Raslanas et al., 2010; etc.).

Passive house involves a number of interested parties (i.e. clients, users, designers, contractors, suppliers, maintenance organisations, local authorities, government and its institutions, etc.) pursuing various goals as well as having different potentialities, educational level and experience. This leads to various approaches of the above parties to decision making in this field. In order to thoroughly analyze the alternatives available and obtain an efficient compromise solution it is often necessary to define them on the basis of economic, qualitative, legal, social, technical, technological and other type of information. This information should be provided in a most user-oriented way.

The presentation of information needed for decision making in PHDMCDS system may be in conceptual (digital (numerical), textual, graphical (diagrams, graphs, drawing, etc), photographical, sound, visual (video)) and quantitative forms. Thus, quantitative information presentation involves criteria systems and subsystems, units of measurement, values and initial weights fully defining the variants provided. Conceptual information means a conceptual description of the alternative solutions, the criteria and ways of determining their values and weights, etc.

In this way, PHDMCDS system enables the decision maker to get various conceptual and quantitative information on passive house from a database and a model-base allowing him to analyze the above factors and make an efficient solution.

The analysis of database structures in decision support systems according to the type of problem solved reveals their various utility. There are three basic types of database structures: hierarchical, network and relational. PHDMCDS system has a relational database structure when the information is stored in the form of tables. These tables contain quantitative and conceptual information. Each table is given a name and is saved in the computer external memory as a separate file. Logically linked parts of the table make a relational model. The following tables make PHDMCDS system database:

- Initial data tables. These contain general facts about the passive house.
- Tables assessing passive house solutions. They contain quantitative and conceptual information about alternative passive house solutions relating to passive house enclosures, engineering systems, utilities, space planning, etc.
- Tables of multivariant design. They provide quantitative and conceptual information on the interconnection of the elements to be designed, their compatibility and possible combinations as well as data on complex multivariant design of a passive house.

To design the structure of a database and perform its completion, storage, editing, navigation, searching, browsing, etc. a database management system was used.

The tables assessing passive house solutions contain the variants available and their quantitative and conceptual description. Quantitative description of the alternatives deals with the systems and subsystems of criteria fully defining the variants as well as the units of measurement and values and initial weights. Conceptual description defines the alternatives available in a commonly used language giving the reasons and providing grounds for choosing a particular criterion, calculation its value, significance and the like.

The owner and the occupants of a passive house being constructed have their specific needs and financial situation. Therefore, every time when using PHDMCDS system they may make corrections of the database according to the aims to be achieved and the financial situation available. For example, a certain client considers the sound insulation of the external walls to be more important than their appearance while some other client is quite of the opposite opinion. The client striving to express his attitude towards these issues numerically may ascribe various significance values to them which eventually will affect general estimation of a project. Though this assessment may seem biased and even quite subjective the solution finally made may exactly meet the requirements, aims and affordability of the client.

Uniform types of relational tables have been chosen to facilitate entering of appropriate data into the database. Such unified database also make it possible easily correct and introduce new information as well as efficiently carrying out computation.

The above tables are used as a basis for working out the matrices of decision making. These matrices, along with the use of a model-base and models, make it possible to perform multivariant design and multiple criteria evaluation of alternative passive house projects resulting in the selection of most beneficial variants.

In order to design and realise an effective passive house project the alternatives available should be analysed. Computer-aided multivariant design requires the availability of the tables containing the data on the interconnection of the elements to be constructed and the solutions made as well as their compatibility, possible combination and multivariant design.

Since the objectives and financial situations of PHDMCDS system users often vary the initial design data and, consequently, the results obtained will also be different. Therefore, the objectives and the financial situation of the clients are expressed quantitatively and provided as the initial data for calculations. These data should be related to the other information of the tables. Based on the above tables of multivariant passive house design possible passive house variants are being developed. When using a method of multivariant design suggested by the authors until 100000 alternative passive house projects may be obtained. These project versions are checked for their capacity to meet various requirements. Those which can not satisfy these requirements raised are excluded from further consideration. In designing a number of variants of passive house the problem of significance compatibility of the criteria arises. In this case, when a complex evaluation of the alternatives is carried out the value of a criterion weight is dependent on the overall criteria being assessed as well as on their values and initial weight.

Since the efficiency of a passive house variant is often determined taking into account economic, aesthetic, technical, comfortability, legal, social and other factors a model-base of a decision support system should include models enabling a decision maker to do a comprehensive analysis of the variants available and make a proper choice. The following models of model-base are aimed to perform this function:

- a model for determining the initial weights of the criteria (with the use of expert methods),
- a model for the criteria weight establishment,
- a model for multivariant design of a passive house,

– a model for multiple criteria analysis and setting the priorities,
– a model for determination of project utility degree,
– a model for providing recommendations.

Based on the above models, a PHDMCDS system can make until 100,000 passive house alternative versions, performing their multiple criteria analysis, determining utility degree and selecting most beneficial variant without human interference.

A management system of the PHDMCDS model base provides the user with a model base allowing him to modify the models available, eliminating those which are no longer needed and adding some new models linked with the existing ones.

The more alternative versions are investigated before making a final decision, the greater is the possibility to achieve a more rational end result. Basing oneself on possessed information and the PHDMCDS system it is possible to perform multiple criteria analysis of passive house projects components (walls, windows, roof, floors, volumetric planning, engineering systems, etc.) and select the most efficient versions. After this, the received compatible and rational components of a passive house are joined up into projects. Having performed multiple criteria analysis of projects made up in such a way, one can select the most efficient ones. Strong and weak sides of investigated projects are also given an analysis. Facts of why and by what degree one version is better than the other are also established. All this is done basing oneself on conceptual and quantitative information.

5. CASE STUDY

In order to demonstrate how the PHDMCDS system works and to present its operation and functions, a description of working with the system is presented.

Initially, a client who wants to construct a passive house deals with the selection of the best alternatives of windows, doors, roofs, walls, solar collectors, heat pumps, shading systems, etc. All these procedures are based both on explicit and tacit knowledge.

The initial quantitative and qualitative database (criteria system, values and weights of criteria) of windows, doors, roofs, walls, solar collectors, heat pumps, shading systems, etc. was compiled from the information provided by manufacturers, suppliers, experts and users.

As an example of multiple criteria analysis, we will take the case of windows.

After clicking the mouse on the items "Description of the alternatives" the system provides the user with the initial data necessary for the analysis (see Table 1). The main data on the compared variants are presented in the form of a decision-making matrix, where columns express the discussed alternative variants of windows; and quantitative information is presented in rows, which describe the discussed alternatives in detail.

Table 1 presents the criteria system, criteria measuring units, and values and weights, which describe the discussed alternatives of windows in detail. A user may review all criteria, their values and weights.

A mouse-click on the title of each discussed variant opens a new window on the web-browser, which presents detailed conceptual (textual, photographic) data of the selected variant. When a user activates a particular item, he/she may review additional textual and photographic information on each alternative.

The relation of various types of weights shows the number of times a particular criteria has greater/smaller influence on complex effectiveness of alternatives.

A mouse-click on the menu item "Results of multiple criteria evaluation of the alternatives" makes the system perform the multiple criteria analysis of windows. The calculations determine the utility degree and priorities of the variants (see Table 2).

Table 1. Initial data of multiple criteria analysis of the windows

Tildės Biuras Ieškoti Pažymėti

Qualitative and quantitative description of the alternatives

Quantitative and qualitative information pertinent to alternatives													
Criteria describing the alternatives	*	Measuring units	Weight	Compared alternatives									
				Megrame 1 var.	Megrame 2 var.	Megrame 3 var.	Fakro FTP-V U3	Fakro FTU-V U3	Fakro PPP-V U3	Fakro FTP-V U5	Baltijos langai	Optiwin
Price	-	Lt	0,6	1085	1100	1201	1216	1411	2594	2042	950	1510
Mechanical strength and stiffness	+	points	0,0275	1	1	1	1	1	1	1	1	1
Reliability	+	Cycles	0,0291	20000	20000	20000	10000	10000	10000	10000	10000	10000
Thermal transmission coefficient of profile	-	W/m2K	0,0284	1,2	1,1	1,1	1,4	1,4	1,5	0,97	0,88	1
Thermal transmission coefficient of double glazing unit	-	W/m2K	0,0322	1	1,2	0,9	1	1	1	1	0,73	0,72
Emission ability of low emissive glass coating e	-	points	0,023	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4
Parameter of air sound isolation Rw	+	dB	0,0259	30	32	32	32	33	32	30	34	31
Air leakage, when pressure difference Dp = 50 Pa	-	(m3/m2h)	0,0246	0,5	0,55	0,6	0,3	0,25	0,42	0,5	0,4	0,35
Guarantee period	+	years	0,0302	5	5	5	10	10	10	10	5	5
Durability	+	years	0,0309	50	50	50	50	50	50	50	50	50
Light transmission of double glazing unit	+	%	0,022	74	68	68	75	78	78	72	74	75
Pay-back period	-	years	0,0262	1	1	1	1	1	1	1	1	1
Duration of works	-	days	0,0225	14	14	14	10	10	10	10	14	10
Quantity of windows with two opening positions (horizontal and vertical) (in percent of the area of all windows)	+	%	0,0215	100	100	100	50	50	50	50	100	100
Quantity of windows with closing infiltration air vent or the third opening position (in percent of the area of all windows)	+	%	0,0258	100	100	100	80	80	80	80	100	100

- The sign "" indicates that a greater (less) criterion value corresponds to a greater significance for a user (stakeholders)

Done Internet

Table 2. Fragment of multiple criteria analysis of the windows

Tildės Biuras Ieškoti Pažymėti

Parameter of air sound isolation Rw	+	dB	0,0259	0,0027 AVG MIN	0,0029 AVG MIN	0,0029 AVG MIN	0,0029 AVG MIN	0,003 AVG MIN	0,0029 AVG MIN	0,0027 AVG MIN	0,0031 AVG MIN	0,0028 AVG MIN
Air leakage, when pressure difference Dp = 50 Pa	-	(m3/m2h)	0,0246	0,0032 AVG MIN	0,0035 AVG MIN	0,0038 AVG MIN	0,0019 AVG MIN	0,0016 AVG MIN	0,0027 AVG MIN	0,0032 AVG MIN	0,0025 AVG MIN	0,0022 AVG MIN
Guarantee period	+	years	0,0302	0,0023 AVG MIN	0,0023 AVG MIN	0,0023 AVG MIN	0,0046 AVG MIN	0,0046 AVG MIN	0,0046 AVG MIN	0,0046 AVG MIN	0,0023 AVG MIN	0,0023 AVG MIN
Durability	+	years	0,0309	0,0034 AVG MIN	0,0034 AVG MIN	0,0034 AVG MIN	0,0034 AVG MIN	0,0034 AVG MIN	0,0034 AVG MIN	0,0034 AVG MIN	0,0034 AVG MIN	0,0034 AVG MIN
Light transmission of double glazing unit	+	%	0,022	0,0025 AVG MIN	0,0023 AVG MIN	0,0023 AVG MIN	0,0025 AVG MIN	0,0026 AVG MIN	0,0026 AVG MIN	0,0024 AVG MIN	0,0025 AVG MIN	0,0025 AVG MIN
Pay-back period	-	years	0,0262	0,0029 AVG MIN	0,0029 AVG MIN	0,0029 AVG MIN	0,0029 AVG MIN	0,0029 AVG MIN	0,0029 AVG MIN	0,0029 AVG MIN	0,0029 AVG MIN	0,0029 AVG MIN
Duration of works	-	days	0,0225	0,003 AVG MIN	0,003 AVG MIN	0,003 AVG MIN	0,0021 AVG MIN	0,0021 AVG MIN	0,0021 AVG MIN	0,0021 AVG MIN	0,003 AVG MIN	0,0021 AVG MIN
Quantity of windows with two opening positions (horizontal and vertical) (in percent of the area of all windows)	+	%	0,0215	0,0031 AVG MIN	0,0031 AVG MIN	0,0031 AVG MIN	0,0015 AVG MIN	0,0015 AVG MIN	0,0015 AVG MIN	0,0015 AVG MIN	0,0031 AVG MIN	0,0031 AVG MIN
Quantity of windows with closing infiltration air vent or the third opening position (in percent of the area of all windows)	+	%	0,0258	0,0031 AVG MIN	0,0031 AVG MIN	0,0031 AVG MIN	0,0025 AVG MIN	0,0025 AVG MIN	0,0025 AVG MIN	0,0025 AVG MIN	0,0031 AVG MIN	0,0031 AVG MIN
The sums of weighted normalized maximizing (projects 'pluses') indices of the alternative				0,025	0,025	0,025	0,0229	0,0231	0,023	0,0226	0,023	0,0227
The sums of weighted normalized minimizing (projects 'minuses') indices of the alternative				0,0684	0,0698	0,0737	0,0728	0,0814	0,1368	0,1107	0,0596	0,0843
Significance of the alternative				0,1043	0,1035	0,101	0,1004	0,0944	0,0716	0,0854	0,1349	0,1019
Priority of the alternative				2	3	5	6	7	9	8	1	4
Utility degree of the alternative (%)				77,3%	76,7%	74,85%	74,4%	69,96%	53,06%	63,29%	99,97%	75,52%

- The sign "" indicates that a greater (less) criterion value corresponds to a greater significance for a user (stakeholders)

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After the quantitative assessment alternative is executed multiple criteria analysis of these options shall be carried out. Calculations revealed that the best window with 99,97% efficiency coefficient is Baltijos langai window, the efficiency coefficient of the second product is 77,3%. So the priority of windows has been established. Last window to choose is distinguished by the lowest efficiency, in this case it amounts to 53,06% (see Table 2). The system's multiple criteria model for measuring the utility degree and market value shows what price of an evaluated alternative would make it equally competitive in the market after a complex assessment of all the advantages and disadvantages of the analysed alternatives.

In order to find what price will make the alternatives being valuated competitive on the market a method of determining the utility degree and market value of objects based on the complex analysis of all their benefits and drawbacks was suggested by the authors. According to this method the alternatives utility degree and the market value of an alternatives being estimated are directly proportional to the system of the criteria adequately describing them and the values and significances of these criteria. A fragment of market value analysis of the windows is presented in Table 3.

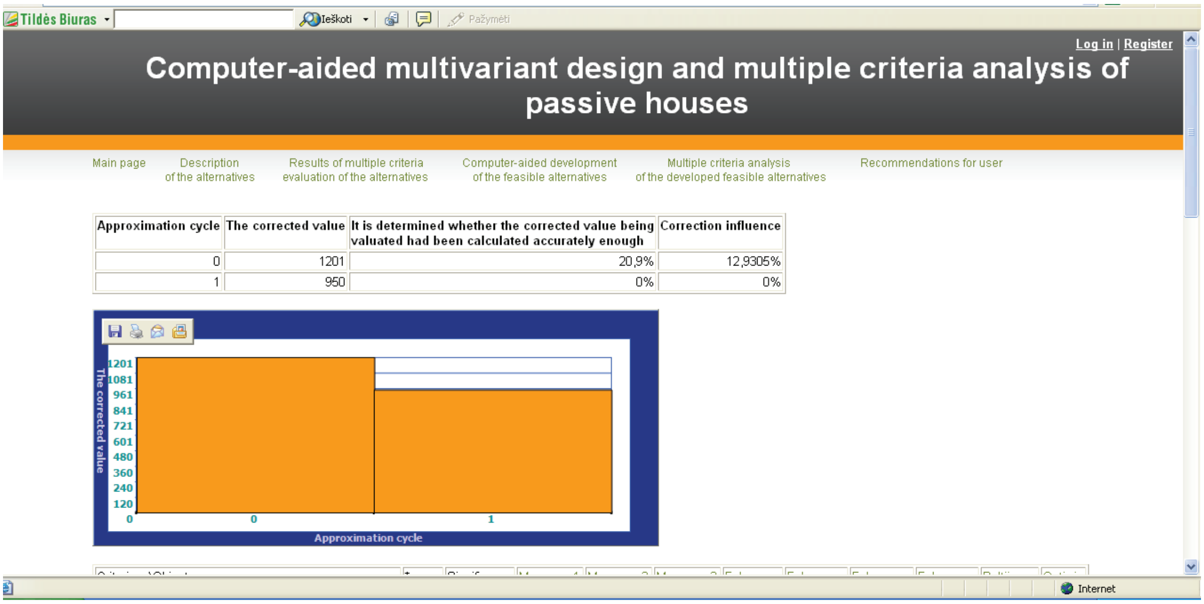
For example, if the window Megrame 3 would cost 950 Lt instead of 1201 Lt, it would be distinguished as market competitive. Compared with the most attractive option its efficiency coefficient would make 82,82% instead of 74,85%. So priority indicator would make this window the second out of nine, now it is the fifth (see Table 2).

After a multiple criteria analysis of windows, doors, heat pumps, roofs, walls, solar collectors, etc., alternative variants are developed in an automated way (see Table 4), and the best alternative combinations are provided. The alternative multiple criteria variant design method developed by authors is used for this purpose.

After the activation of the item "Multiple criteria analysis of the developed alternatives" the multiple criteria analysis of the developed passive house feasible alternatives is performed (see Table 5).

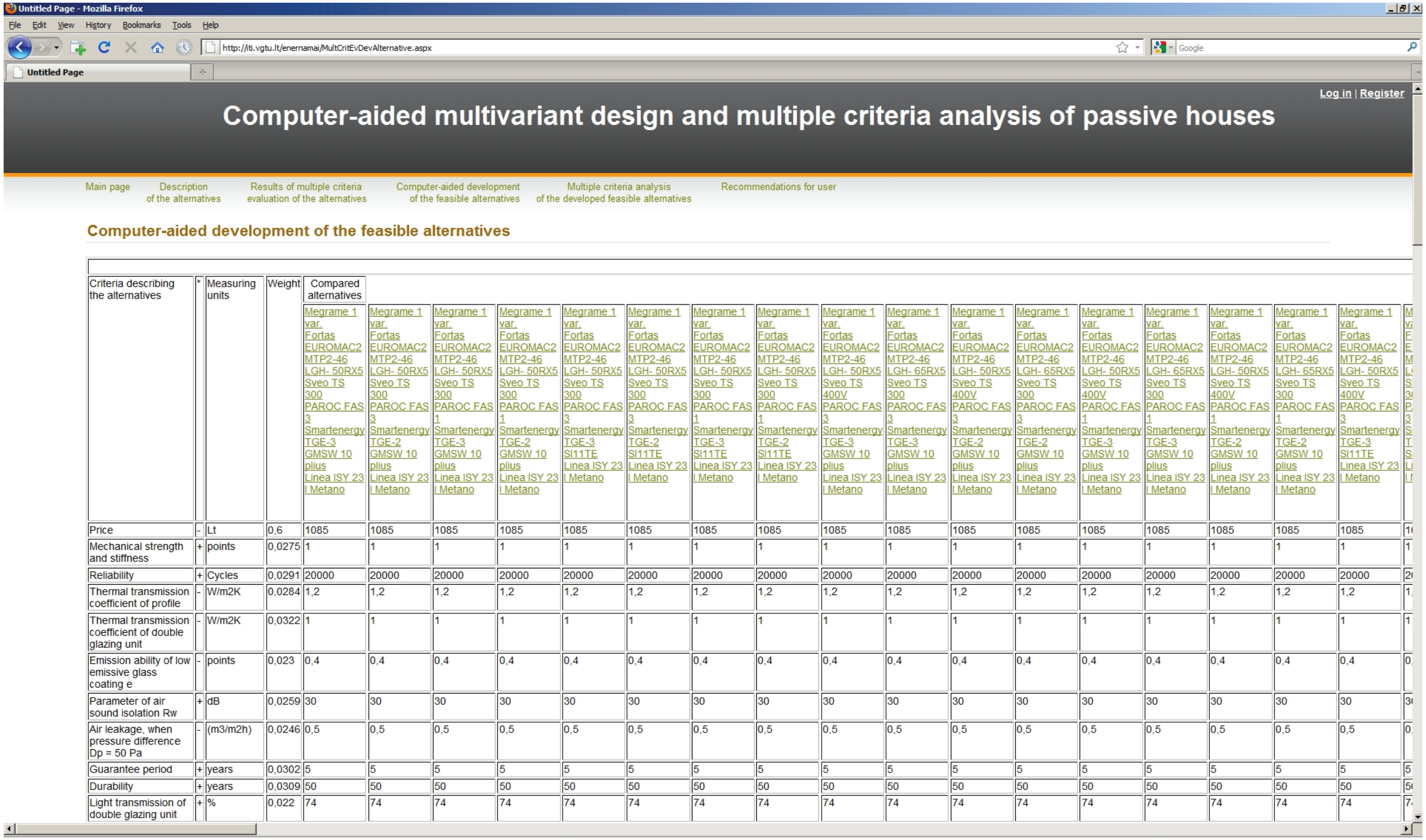
The following processes are automated: multi-criteria analysis of variant combinations, determination of utility degree and priorities and selection of the most efficient variants. Moreover the strengths and weaknesses of the analysed variants are presented; i.e., it is possible to see why and to what extent one alternative is better than is another.

Table 3. Fragment of a market value analysis of the windows



Approximation cycle	The corrected value	It is determined whether the corrected value being valuated had been calculated accurately enough	Correction influence
0	1201	20,9%	12,9305%
1	950	0%	0%

Table 4. Fragment of the computer-aided development of the passive house alternatives



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Computer-aided multivariant design and multiple criteria analysis of passive houses

Main page | Description of the alternatives | Results of multiple criteria evaluation of the alternatives | Computer-aided development of the feasible alternatives | Multiple criteria analysis of the developed feasible alternatives | Recommendations for user

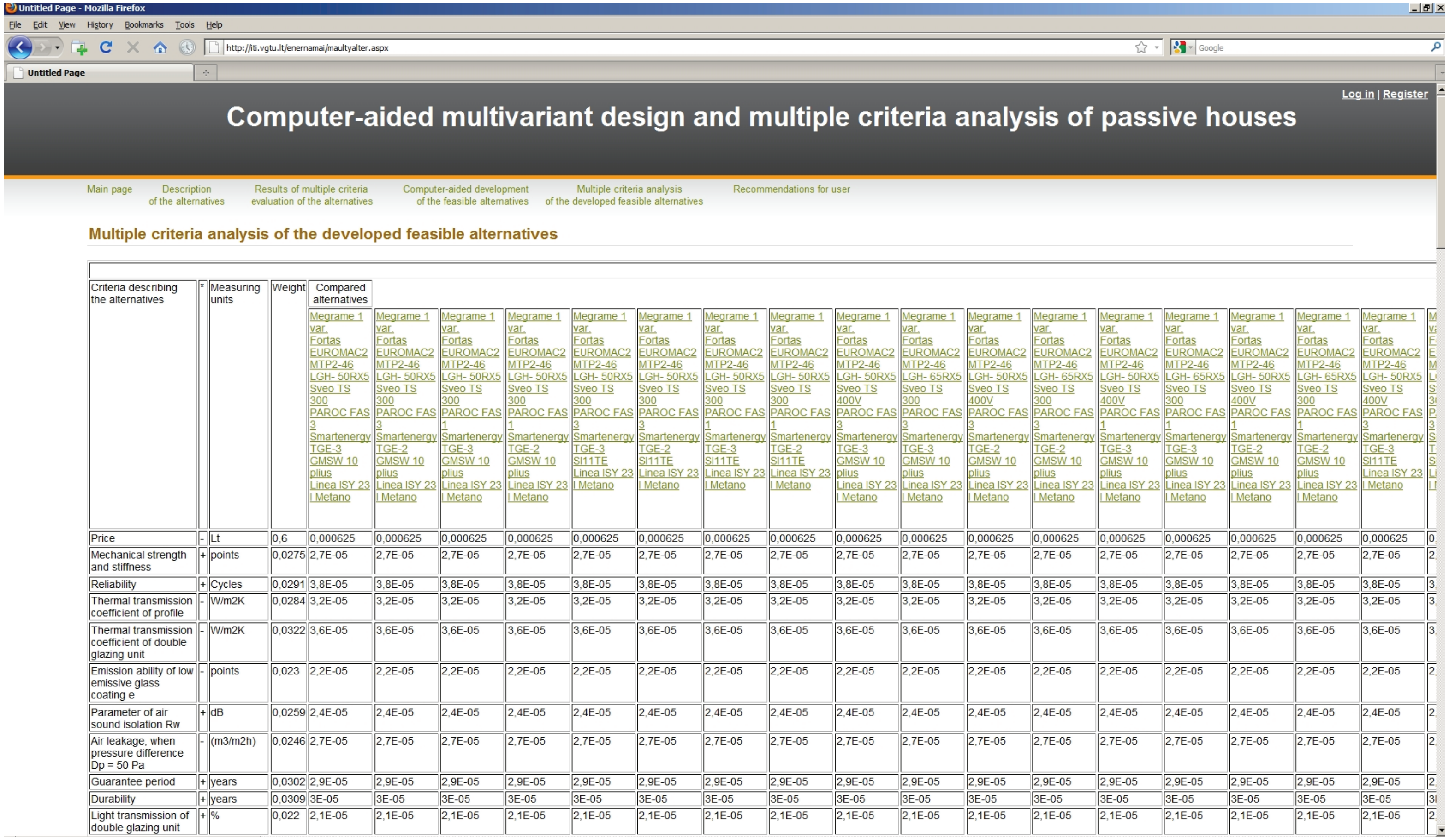
Computer-aided development of the feasible alternatives

Criteria describing the alternatives	*	Measuring units	Weight	Compared alternatives					
				Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 50RX5 Sveo TS 300 PAROC FAS 3 Smartenergy TGE-3 GMSW 10 plius Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 50RX5 Sveo TS 300 PAROC FAS 3 Smartenergy TGE-2 GMSW 10 plius Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 50RX5 Sveo TS 300 PAROC FAS 1 Smartenergy TGE-3 GMSW 10 plius Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 50RX5 Sveo TS 300 PAROC FAS 1 Smartenergy TGE-2 GMSW 10 plius Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 50RX5 Sveo TS 300 PAROC FAS 3 Smartenergy TGE-3 SI11TE Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 50RX5 Sveo TS 300 PAROC FAS 3 Smartenergy TGE-2 SI11TE Linea ISY 23 I Metano
Price	-	Lt	0,6	1085	1085	1085	1085	1085	1085
Mechanical strength and stiffness	+	points	0,0275	1	1	1	1	1	1
Reliability	+	Cycles	0,0291	20000	20000	20000	20000	20000	20000
Thermal transmission coefficient of profile	-	W/m2K	0,0284	1,2	1,2	1,2	1,2	1,2	1,2
Thermal transmission coefficient of double glazing unit	-	W/m2K	0,0322	1	1	1	1	1	1
Emission ability of low emissive glass coating e	-	points	0,023	0,4	0,4	0,4	0,4	0,4	0,4
Parameter of air sound isolation Rw	+	dB	0,0259	30	30	30	30	30	30
Air leakage, when pressure difference Dp = 50 Pa	-	(m3/m2h)	0,0246	0,5	0,5	0,5	0,5	0,5	0,5
Guarantee period	+	years	0,0302	5	5	5	5	5	5
Durability	+	years	0,0309	50	50	50	50	50	50
Light transmission of double glazing unit	+	%	0,022	74	74	74	74	74	74

Criteria describing the alternatives						
	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 50RX5 Sveo TS 300 PAROC FAS 1 Smartenergy TGE-3 SI11TE Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 50RX5 Sveo TS 300 PAROC FAS 1 Smartenergy TGE-2 SI11TE Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 50RX5 Sveo TS 400V PAROC FAS 3 Smartenergy TGE-3 GMSW 10 plius Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 65RX5 Sveo TS 300 PAROC FAS 3 Smartenergy TGE-3 GMSW 10 plius Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 50RX5 Sveo TS 400V PAROC FAS 3 Smartenergy TGE-2 GMSW 10 plius Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 65RX5 Sveo TS 300 PAROC FAS 3 Smartenergy TGE-2 GMSW 10 plius Linea ISY 23 I Metano
Price	1085	1085	1085	1085	1085	1085
Mechanical strength and stiffness	1	1	1	1	1	1
Reliability	20000	20000	20000	20000	20000	20000
Thermal transmission coefficient of profile	1,2	1,2	1,2	1,2	1,2	1,2
Thermal transmission coefficient of double glazing unit	1	1	1	1	1	1
Emission ability of low emissive glass coating e	0,4	0,4	0,4	0,4	0,4	0,4
Parameter of air sound isolation Rw	30	30	30	30	30	30
Air leakage, when pressure difference Dp = 50 Pa	0,5	0,5	0,5	0,5	0,5	0,5
Guarantee period	5	5	5	5	5	5
Durability	50	50	50	50	50	50
Light transmission of double glazing unit	74	74	74	74	74	74

Criteria describing the alternatives						
	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 50RX5 Sveo TS 400V PAROC FAS 1 Smartenergy TGE-3 GMSW 10 plius Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 65RX5 Sveo TS 300 PAROC FAS 1 Smartenergy TGE-3 GMSW 10 plius Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 50RX5 Sveo TS 400V PAROC FAS 1 Smartenergy TGE-2 GMSW 10 plius Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 65RX5 Sveo TS 300 PAROC FAS 1 Smartenergy TGE-2 GMSW 10 plius Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 50RX5 Sveo TS 400V PAROC FAS 3 Smartenergy TGE-3 SI11TE Linea ISY 23 I Metano	M va F E M L S 3 P 3 S T S Li I I
Price	1085	1085	1085	1085	1085	1
Mechanical strength and stiffness	1	1	1	1	1	1
Reliability	20000	20000	20000	20000	20000	2
Thermal transmission coefficient of profile	1,2	1,2	1,2	1,2	1,2	1,
Thermal transmission coefficient of double glazing unit	1	1	1	1	1	1
Emission ability of low emissive glass coating e	0,4	0,4	0,4	0,4	0,4	0,
Parameter of air sound isolation Rw	30	30	30	30	30	3
Air leakage, when pressure difference Dp = 50 Pa	0,5	0,5	0,5	0,5	0,5	0,
Guarantee period	5	5	5	5	5	5
Durability	50	50	50	50	50	5
Light transmission of double glazing unit	74	74	74	74	74	7.

Table 5. Fragment of multiple criteria analysis of the developed passive house feasible alternatives



Criteria describing the alternatives	*	Measuring units	Weight	Compared alternatives								
				Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 50RX5 Sveo TS 300 PAROC FAS 3 Smartenergy TGE-3 GMSW 10 plius Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 50RX5 Sveo TS 300 PAROC FAS 3 Smartenergy TGE-2 GMSW 10 plius Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 50RX5 Sveo TS 300 PAROC FAS 1 Smartenergy TGE-3 GMSW 10 plius Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 50RX5 Sveo TS 300 PAROC FAS 1 Smartenergy TGE-2 GMSW 10 plius Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 50RX5 Sveo TS 300 PAROC FAS 3 Smartenergy TGE-3 SI11TE Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 50RX5 Sveo TS 300 PAROC FAS 3 Smartenergy TGE-2 SI11TE Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 50RX5 Sveo TS 300 PAROC FAS 1 Smartenergy TGE-3 SI11TE Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 50RX5 Sveo TS 300 PAROC FAS 1 Smartenergy TGE-2 SI11TE Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 50RX5 Sveo TS 400V PAROC FAS 3 Smartenergy TGE-3 GMSW 10 plius Linea ISY 23 I Metano
Price	-	Lt	0,6	0,000625	0,000625	0,000625	0,000625	0,000625	0,000625	0,000625	0,000625	0,000625
Mechanical strength and stiffness	+	points	0,0275	2,7E-05	2,7E-05	2,7E-05	2,7E-05	2,7E-05	2,7E-05	2,7E-05	2,7E-05	2,7E-05
Reliability	+	Cycles	0,0291	3,8E-05	3,8E-05	3,8E-05	3,8E-05	3,8E-05	3,8E-05	3,8E-05	3,8E-05	3,8E-05
Thermal transmission coefficient of profile	-	W/m2K	0,0284	3,2E-05	3,2E-05	3,2E-05	3,2E-05	3,2E-05	3,2E-05	3,2E-05	3,2E-05	3,2E-05
Thermal transmission coefficient of double glazing unit	-	W/m2K	0,0322	3,6E-05	3,6E-05	3,6E-05	3,6E-05	3,6E-05	3,6E-05	3,6E-05	3,6E-05	3,6E-05
Emission ability of low emissive glass coating e	-	points	0,023	2,2E-05	2,2E-05	2,2E-05	2,2E-05	2,2E-05	2,2E-05	2,2E-05	2,2E-05	2,2E-05
Parameter of air sound isolation Rw	+	dB	0,0259	2,4E-05	2,4E-05	2,4E-05	2,4E-05	2,4E-05	2,4E-05	2,4E-05	2,4E-05	2,4E-05
Air leakage, when pressure difference Dp = 50 Pa	-	(m3/m2h)	0,0246	2,7E-05	2,7E-05	2,7E-05	2,7E-05	2,7E-05	2,7E-05	2,7E-05	2,7E-05	2,7E-05
Guarantee period	+	years	0,0302	2,9E-05	2,9E-05	2,9E-05	2,9E-05	2,9E-05	2,9E-05	2,9E-05	2,9E-05	2,9E-05
Durability	+	years	0,0309	3E-05	3E-05	3E-05	3E-05	3E-05	3E-05	3E-05	3E-05	3E-05
Light transmission of double glazing unit	+	%	0,022	2,1E-05	2,1E-05	2,1E-05	2,1E-05	2,1E-05	2,1E-05	2,1E-05	2,1E-05	2,1E-05

Criteria describing the alternatives									
	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 65RX5 Sveo TS 300 PAROC FAS 3 Smartenergy TGE-3 GMSW 10 plius Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 50RX5 Sveo TS 400V PAROC FAS 3 Smartenergy TGE-2 GMSW 10 plius Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 65RX5 Sveo TS 300 PAROC FAS 3 Smartenergy TGE-2 GMSW 10 plius Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 50RX5 Sveo TS 400V PAROC FAS 1 Smartenergy TGE-3 GMSW 10 plius Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 65RX5 Sveo TS 300 PAROC FAS 1 Smartenergy TGE-3 GMSW 10 plius Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 50RX5 Sveo TS 400V PAROC FAS 1 Smartenergy TGE-2 GMSW 10 plius Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 65RX5 Sveo TS 300 PAROC FAS 1 Smartenergy TGE-2 GMSW 10 plius Linea ISY 23 I Metano	Megrame 1 var. Fortas EUROMAC2 MTP2-46 LGH- 50RX5 Sveo TS 400V PAROC FAS 3 Smartenergy TGE-3 SI11TE Linea ISY 23 I Metano	M va F E M L S 3 P 3 S T S Li I
Price	0,000625	0,000625	0,000625	0,000625	0,000625	0,000625	0,000625	0,000625	0
Mechanical strength and stiffness	2,7E-05	2,7E-05	2,7E-05	2,7E-05	2,7E-05	2,7E-05	2,7E-05	2,7E-05	2
Reliability	3,8E-05	3,8E-05	3,8E-05	3,8E-05	3,8E-05	3,8E-05	3,8E-05	3,8E-05	3
Thermal transmission coefficient of profile	3,2E-05	3,2E-05	3,2E-05	3,2E-05	3,2E-05	3,2E-05	3,2E-05	3,2E-05	3
Thermal transmission coefficient of double glazing unit	3,6E-05	3,6E-05	3,6E-05	3,6E-05	3,6E-05	3,6E-05	3,6E-05	3,6E-05	3
Emission ability of low emissive glass coating e	2,2E-05	2,2E-05	2,2E-05	2,2E-05	2,2E-05	2,2E-05	2,2E-05	2,2E-05	2
Parameter of air sound isolation Rw	2,4E-05	2,4E-05	2,4E-05	2,4E-05	2,4E-05	2,4E-05	2,4E-05	2,4E-05	2
Air leakage, when pressure difference Dp = 50 Pa	2,7E-05	2,7E-05	2,7E-05	2,7E-05	2,7E-05	2,7E-05	2,7E-05	2,7E-05	2
Guarantee period	2,9E-05	2,9E-05	2,9E-05	2,9E-05	2,9E-05	2,9E-05	2,9E-05	2,9E-05	2
Durability	3E-05	3E-05	3E-05	3E-05	3E-05	3E-05	3E-05	3E-05	3
Light transmission of double glazing unit	2,1E-05	2,1E-05	2,1E-05	2,1E-05	2,1E-05	2,1E-05	2,1E-05	2,1E-05	2

6. CONCLUSIONS

In order to improve energy efficient construction must rest on an integrated analysis and rational decision-making at the micro, meso and macro levels. In addition to economic, political and legal/regulatory decisions, other aspects of social, culture, ethical, psychological, educational, environmental, provision, technological, technical, organizational and managerial, should be considered as well. Therefore above energy efficient construction instruments are under improvement and adapted according to above micro, meso and macro levels factors. It is advisable to make better use of the explicit and tacit knowledge throughout the passive house lifecycle in Lithuania.

Having analysed projects and published articles of individual scientists we may claim that usually they specialize in only one narrow field (e.g., valuation of heat conduction coefficient of windows, walls and roofing, energy efficiency). Several scientists attempted to analyze the bonds between design and realization project groups.

The passive house model suggested by the authors differs from analogous models proposed by other authors by the analysis object and applied multiple criteria analysis methods. Dealing with various issues of passive houses scientists from different countries in their works omitted analysis of the research object as the authors did.

Passive house complex databases are complied, which holistically describe the alternatives from the point of view of technical, qualitative, security, functionality, technological and other aspects. A system created based on these complex databases makes provisions for complex analysis of passive house projects by means of quantitative and qualitative forms.

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SANTRAUKA

INTEGRUOTAS PASYVIŲJŲ NAMŲ DAUGIAKRITERINĖS ANALIZĖS MODELIS IR SISTEMA

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Norint suprojektuoti ir įgyvendinti kokybišką pasyvųjį namą, reikia jo efektyvumu rūpintis nuo projekto idėjos iki pasyviojo namo gyvavimo ciklo pabaigos. Visas procesas turi būti suplanuotas ir įgyvendintas atsižvelgiant į suinteresuotų projekto grupių siekiamus tikslus ir mikro-, mezo- bei makroaplinką. Tikslams įgyvendinti buvo sukurtas originalus integruotas pasyviųjų namų analizės modelis ir pasyviųjų namų projektų analizės daugiakriterinė sprendimų paramos sistema, kuria remiantis galima analizuoti pasyviojo namo gyvavimo ciklą, suinteresuotas projekto grupes ir projekto mikro-, mezo- bei makroaplinką kaip vieną integruotą visumą.