VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

Jevgenija RUTĖ

KNOWLEDGE MODEL AND MULTIPLE CRITERIA DECISION SUPPORT SYSTEM FOR PASSIVE HOUSES

DOCTORAL DISSERTATION

TECHNOLOGICAL SCIENCES,
CIVIL ENGINEERING (02T)

VGTU
LEIDYKLA
Vilnius TECHNIKA 2013

Doctoral dissertation was prepared at Vilnius Gediminas Technical University in 2008–2013.

Scientific Supervisor

Assoc Prof Dr Audrius BANAITIS (Vilnius Gediminas Technical University, Technological Sciences, Civil Engineering – 02T).

http://leidykla.vgtu.lt
VGTU leidyklos TECHNIKA 2191-M mokslo literatūros knyga

ISBN 978-609-457-581-5

© VGTU leidykla TECHNIKA, 2013
© Jevgenija Rutė, 2013
jevgenija.rute@ku.lt

VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

Jevgenija RUTĖ

PASYVIŲJŲ NAMŲ ŽINIŲ MODELIS IR DAUGIAKRITERINĖ SPRENDIMŲ PARAMOS SISTEMA

DAKTARO DISERTACIJA

TECHNOLOGIJOS MOKSLAI,
STATYBOS INŽINERIJA (02T)

LEIDYKLA
Vilnius TECHNIKA 2013

Disertacija rengta 2008–2013 metais Vilniaus Gedimino technikos universitete.

Mokslinis vadovas

doc. dr. Audrius BANAITIS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, statybos inžinerija – 02T).

Abstract

The research object is a complex evaluation of passive houses knowledge and decision making, also interested parties striving to attain their goals and micro, mezzo and macro environments as integral whole. As a tool for complex evaluation of passive houses knowledge and in decision making to select the most effective alternative, a multiple criteria decision support system is being suggested. The main goal of the thesis is to create a passive houses knowledge model and to create a decision support system in choosing a passive house alternative using multiple criteria analysis and multiple criteria multivariant design methods.

The dissertation comprises an introduction, three chapters, general conclusions, a list of references, and a list of the author's publications on the topic of this dissertation.

The introduction discusses the research problem and relevance, describes the research object, states the research goal and tasks, outlines the research methodology and original scientific novelty, points out the practical significance of the research findings, and states the propositions to be defended. The introduction ends with an overview of the author's articles and conference presentations on the topic of this dissertation, and an outline of the dissertation's structure.

Chapter 1 presents a review of the scientific literature and an analysis of the knowledge and models related to passive houses.

Chapter 2 presents the conceptual passive houses knowledge model developed by the author, describes its main elements in detail, and discusses their interactions.

Chapter 3 deals with multivariant design and multiple criteria analysis of the components of a passive houses. It reviews the preparation procedure for input data, describes the suggested model for multivariant design and multiple criteria analysis of the components of passive houses, and presents the process and methodology of analysis. Multiple criteria decision support system for passive houses knowledge designed on the basis of the model proposed by the author. The chapter deals in detail with the system's elements and explains the principle of its operation.

The main research findings were discussed in two scientific conferences. The findings of the thesis were outlined in five scientific publications, including two articles listed in scientific journals listed in the *Thomson Reuters ISI Web of Science*, two articles in the scientific journals, and one article in peer-reviewed conference proceedings.

Reziumė

Disertacijos tyrimų objektą sudaro kompleksinis pasyviųjų namų žinių vertinimas ir sprendimų priėmimas, jame dalyvaujančios ir savo tikslus norinčios įgyvendinti suinteresuotos grupės bei išorinė mikro-, mezo- ir makrolygmens aplinka kaip visuma. Kaip pasyviųjų namų žinių kompleksinio vertinimo ir sprendimo priimti efektyviausią pasyviojo namo variantą priemonė siūloma daugiakriterinė sprendimų paramos sistema. Darbo tikslas – sukurti pasyviųjų namų žinių modelį ir, taikant šį modelį, sukurti pasyviųjų namų variantų parinkimo sprendimų paramos sistemą, kurioje taikomi daugiakriterinės analizės ir daugiakriterinio alternatyvaus projektavimo metodai.

Disertaciją sudaro įvadas, trys skyriai, rezultatų apibendrinimas, naudotos literatūros ir autorės mokslinių publikacijų disertacijos tema sąrašai.

Įvadiniame skyriuje aptariama tiriamoji problema, darbo aktualumas, aprašomas tyrimų objektas, formuluojamas darbo tikslas bei uždaviniai, aprašoma tyrimų metodika, darbo mokslinis naujumas, darbo rezultatų praktinė reikšmė, ginamieji teiginiai. Įvado pabaigoje pristatomos disertacijos tema autorės paskelbtos mokslinės publikacijos ir pranešimai konferencijose bei disertacijos struktūra.

Pirmajame skyriuje apžvelgiama mokslinė literatūra. Atlikta pasyviųjų namų žinių bei modelių analizė.

Antrajame skyriuje pateikiamas autorės sukurtas koncepcinis pasyviųjų namų žinių modelis, išsamiai aprašyti pagrindiniai modelio elementai, aptarta jų tarpusavio sąveika.

Trečiajame skyriuje atliekamas pasyviųjų namų sudėtinių dalių variantinis projektavimas ir daugiakriterinė analizė. Pateikiamas pradinių duomenų paruošimo procesas, aprašomas pasiūlytas pasyviųjų namų sudėtinių dalių variantinio projektavimo ir daugiakriterinės analizės modelis, analizės eiga bei metodai. Aprašoma pagal autorės pasiūlytą žinių modelį sukurta pasyviųjų namų daugiakriterinė sprendimų paramos sistema. Šiame skyriuje detaliai aprašytos sistemos sudedamosios dalys. Aiškinamas sistemos veikimo principas.

Pagrindiniai darbo rezultatai buvo aptarti dviejose mokslinėse konferencijose. Darbo rezultatai pateikti penkiose mokslinėse publikacijose: iš kurių du – straipsniai žurnaluose, įtrauktuose į *Thomson Reuters ISI Web of Science* duomenų bazę; du – straipsniai recenzuojamuose mokslo žurnaluose, vienas – straipsnis recenzuojamoje konferencijos medžiagoje.

Notations

Symbols

a_j	–	the jth alternative;
c	–	is the number of i solution alternatives to be used in developing a PHK;
D	–	normalized decision making matrix;
d_{ij}	–	the normalized weighted alternative value;sum of dimensionless weighted index values;
m	–	the number of criterion the number of quantitative criteria;
n	–	the number of alternativesthe number of the alternatives compared;
N_j	–	the utility degreeof the jth alternative (COPRAS method);
P	–	initial decisios-making matrix;
q_i	–	significance of i-th criterion;
Q_j	–	relative significance;
S	–	total square deviation;
S_{+j}	–	sum of maximizing criterion (COPRAS method);
S-j	–	sum of minimizing criterion (COPRAS method);
S_{-min}	–	minimal sum of minimizing criterion (COPRAS method);
x_i	–	i-th criterion;
x_{ij}	–	value of the criterion j of the solution i in the variant j.

Abrevations

BEopt1	–	Building Energy Optimization (BEopt);
COPRAS	–	A Method of Multiple Criteria Complex Proportional Evaluation;
DSS	–	Decision Support System;
EGUSA2	–	Energy Gauge USA (EGUSA);
IDES-EDU	–	Master and Post Graduate Education and Training in Multi-disciplinary Teams;
KM	–	Knowledge Management;
MCDM	–	Multiple-Criteria Decision-Making;
MCDA	–	Multiple-Criteria Decision Analysis;
NorthPass	–	Promotion of the Very Low Energy House Concept to the North European Building Market;
PIHI	–	Predicted Indoor Habitability Index;
PEST	–	Political, Economic, Social and Technological;
PHAIC	–	Passive Hhouse and its Ccomponents;
PHK	–	Passive Houses Knowledge;
SRP	–	Scientific Research Programme;
ZEB	–	Zero Energy Building.

Contents

INTRODUCTION 1
The investigated problem 1
Importance of the thesis 1
The object of research 2
The goal of the thesis 2
The tasks of the thesis 3
Research methodology 3
Scientific novelty 3
Practical significance of achieved results 4
The defendable statements 4
Approval of the results 4
Scope of the thesis 5

1. REVIEW OF THE SCIENTIFIC LITERATURE ON PASSIVE HOUSES 7
1.1. The analysis of research for passive houses 7
1.2. Political, economic, socio-cultural and technological aspects in the construction of passive houses around the world 19
1.3. Global practice related to passive houses and practical use of the available knowledge 26
1.4. Decision-making models and methods 29
1.5. Conclusions from Chapter 1 34

2. DEVELOPMENT OF A CONCEPTUAL PASSIVE HOUSES KNOWLEDGE MODEL 35
2.1. The concept of the passive houses knowledge model 35
2.2. Passive houses knowledge model for quantitative and qualitative analyses 36
2.3. Passive houses socio-cultural aspects 38

2.4. Self-expression values, environmentalism, global warming and the passive houses 45
2.4.1. Self-expression values and environmentalism 45
2.4.2. Passive houses, global warming, zero carbon emissions and self-expression values 46
2.5. Passive houses weaknesses in Lithuania 51
2.6. Conclusions from Chapter 2 53

3. MULTIPLE CRITERIA DECISION SUPPORT SYSTEM FOR PASSIVE HOUSES KNOWLEDGE 55
3.1. Gathering of initial data for multiple criteria analysis 55
3.2. Adapted method of multivariant design and multiple criteria analysis of passive houses and its components 57
3.2.1. Determination of the significance, utility degree and priority of all the passive house and its components 58
3.2.2. Multivariant design and multiple criteria analysis of the whole passive houses knowledge 61
3.3. Components of the decision support system for passive houses knowledge 68
3.3.1. Database management subsystem 69
3.3.2. Model-base management subsystem 70
3.4. Multivariant design and multiple criteria analysis of the whole passive house 77
3.5. Case study 77
3.6. Conclusions from Chapter 3 88

GENERAL CONCLUSIONS 91

REFERENCES 93

LIST OF THE AUTHOR'S SCIENTIFIC PUBLICATIONS ON THE TOPIC OF DISSERTATION 103

Introduction

The Investigated problem

The research problem focuses on passive houses knowledge system and decision making, based on multiple criteria analysis methods and information technologies.

Importance of the thesis

Energy saving and refurbishment of buildings is one of the central problems in both developed countries and in Eastern and Central Europe. At the present, numerous buildings in Lithuania's housing stock are in poor or very poor condition. Ways to optimise a building's maintenance costs are increasingly relevant in Lithuania. People opt for warmer housing and seek information about the newest solutions related to utility systems. They are looking for the best ways to optimise heating costs, to cut them at least several times, rather than just by 10–20%.

A passive house with high thermal resistance and cost efficiency might be developed through an integrated use of optimal architectural, construction and engineering solutions, by seeking better materials, and by improving and

accumulating the construction know-how. The market conditions permitting, any available knowledge needs to be structured. A wide variety of passive houses knowledge models have been developed in Lithuania and other countries across the globe, however, these do not contain all the elements necessary to make complex evaluations in decision making process.

Multiple criteria passive houses knowledge decision support system with a view on self-expression values:

- allows to compare the cost-efficiency of buildings, to determine their utility degree and market value, and to estimate and assess the weight each criterion carries to a stakeholder group;
- improves and builds knowledge about new trends in construction;
- cuts energy consumption in buildings and improves quality of life;
- aids to develop best practices,
- encourages people to keep up with the variations of new factors of the construction trends, and to understand and assess the advantages of their future homes;
- allows future occupants to determine the significant factors of their living environment,
- educates, acts as a source of the basic and extended knowledge on the development of energy-efficient houses, and makes the general public aware of passive houses.

The object of research

The research object is a complex evaluation of passive houses knowledge and decision making, also interested parties striving to attain their goals and micro, mezzo and macro environments as integral whole. As a tool for complex evaluation of passive house knowledge and in decision making to select the most effective alternative, a multiple criteria decision support system is being suggested.

The goal of the thesis

The main task of the work is to create a passive houses knowledge model and to create a decision support system in choosing a passive house alternative using multiple criteria analysis and multiple criteria multivariant design methods.

The tasks of the thesis

To achieve the goal of the thesis the following tasks must be solved:

1. Review of research on passive houses in other countries and their results.
2. Create a model for the passive houses knowledge complex analysis.
3. Apply to this model methods of multivariant design and multiple criteria analysis.
4. Establish the content and basis of the database management and model-base management subsystems for the passive houses knowledge multiple criteria decision support system.
5. Integrate these subsystems into passive house knowledge multiple criteria decision support system.
6. Verify the integrity of this decision support system.

Research methodology

The research methodology is based on the analysis of publications in this field published by Lithuanian and foreign authors. In the research data processing methods of project multi criteria analysis and multivariant design, created by Prof Dr Habil E. K. Zavadskas and Prof Dr Habil A. Kaklauskas, were adapted and applied, as well as methods of comparative analysis, expert evaluation, logic and synthesis.

Scientific novelty

1. An original model of passive houses knowledge was designed; its elements were discussed in detail.
2. Multivariant design and multi criteria analysis methods were applied in this model.
3. Model-base management and database management subsystems for passive houses knowledge multiple criteria decision support system were established.

4. Original passive houses knowledge model was created and integrated with passive houses knowledge multiple criteria decision support system.

Practical significance of achieved results

The developed knowledge model and multiple criteria decision support system can be used in evaluation of passive house alternatives, composition of rational alternative selections of passive house components, establishing level of their efficacy, utility degree, market value, and eventually making the right decision.

The main research findings were practically employed implementing international Intelligent Energy Europe projects *NorthPass* and *IDES-EDU*.

The defendable statements

1. Established passive houses knowledge model allows implementing complex view of passive houses, and supplements decision making process with more data, which in turn fosters a more rational and safe choice of passive house version.
2. To make an integrated analysis of alternative options of passive houses knowledge and to facilitate efficient decision-making, such methods as the multivariant design and the multiple criteria analysis may be employed.
3. The developed passive houses knowledge multiple criteria decision support system allows evaluation of passive house alternatives, composition of rational alternative selections of passive house components, establishing level of their efficacy, utility degree, market value, and eventually making the right decision.

Approval of the results

The material presented in the thesis was published in five scientific articles: two in scientific journals listed in the *Thomson Reuters ISI Web of Science*, two in the scientific journals and one in the refereed conference material.

The main findings of the work were discussed in two scientific conferences in Lithuania:

- in the conference of young scientists “Science – Future of Lithuania” 2011, Vilnius;
- in the 7th scientific conference “Scientific Technology Works in Western Lithuania” 2010, Klaipėda.

Scope of the thesis

The dissertation consists of an introduction, three chapters, conclusions and suggestions, and the list of references.

The total scope of dissertation is 116 pages, 10 numbered formulas are used, 20 figures and 17 tables. 144 literature sources have been used while writing the dissertation.

1

Review of the scientific literature on passive houses

In this chapter a review of the scientific literature and an analysis of the knowledge and models related to passive houses are presented.

On the thematic of this chapter 3 publications (Rutė *et al.* 2010; Rutė *et al.* 2011; Matuliauskaitė *et al.* 2011) were published.

1.1. The analysis of research for passive houses

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).

The low energy approach should be the key concept in any long-term strategy aiming to build sustainability. In Europe already more than 6000 passive house units have been successfully built and completed. Positive feedback from inhabitants has confirmed what had been projected: not only energy costs can be reduced drastically, but also the comfort of living increases significantly by using an energy efficient construction. Energy efficiency is the key to high thermal comfort as well as very low energy costs. Excellent insulation, high quality windows and heat recovery make it possible not only to reduce the energy requirement just a little bit, but to substitute the main part of the demand. Products suitable for passive houses have been developed in Europe, can be produced locally and installed by local handycrafts. And such products can be used in refurbishment of existing buildings, too (*The next Passive house* 2008).

The UK government set itself a 60% reduction of carbon dioxide emissions target on 2000 levels by 2050. This commitment will require carbon reductions to be made by all industries including the housing sector which presently accounts for 27% of carbon dioxide emissions. The house building industry is the subject of numerous government policies and legislation, but none are as demanding as the Code of Sustainable Homes, which set a ‘world-beating’ target for all new homes to be zero carbon by 2016. Osmani and O'Reilly (2009) investigates the feasibility of building zero carbon homes in England by 2016 from a house builder's perspective. A comprehensive opinion of the feasibility of zero carbon homes is gathered through a questionnaire survey and in-depth semi-structured interviews with the major UK housing developers. The 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 house builders surveyed concurred that these challenges are not insurmountable provided that a swift, all-embracing and above all realistic strategy is adopted and implemented across the supply chain (Osmani, O'Reilly 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 (Schnieders, Hermelink 2006).

Those working to promote low-energy and passive houses in Norway seem to have managed to break out of the traditional problems innovations meet in the construction sector. This has been done by breaking with traditional ways of running energy efficiency policies. Instead of focusing on the economically rational agent, focus has been turned to the knowledge and thinking of the producers, those that are the intermediaries between national policies and the individual choices. In an industry with many elements and little interaction between the different elements, understanding that the consumer is not able to function as the driving agent of change has been important. The relative success of the promotion of low-energy houses comes as consequence of the successful work that has been done to join the forces of different elements in the innovation system. Government agencies, research institutes as well as business organizations have worked together to promote the houses. Only by joining forces have they been able to overcome the obstacles traditionally seen in this fragmented industry. There is, however, still a lot of work to be done. Certain elements of the innovation system are not yet involved in the development of low-energy and passive houses. The architects are one prominent example. The low-energy allies have to little extent managed to convince this important group of the importance of designing energy efficient houses. The consumers have little knowledge of the concepts, and lack an easily understandable quality control system. In the education of engineers and architects passive and lowenergy houses still need to be included in the curriculum. Even among the elements that are involved in low-energy and passive houses, there is a lot of ground to be broken. Few low-energy houses have been constructed yet, and no passive houses. The producers are interested, but need to be even more convinced of the technological feasibility and economical viability of the passive house (Halse 2007).

High end-user satisfaction levels are key for the acceptance of nearly zero-energy housing. Post-occupancy evaluation research on highly energy-efficient dwellings can lead to recommendations which will influence their performance in the expected future large volume market of such houses. The study by Mlecnik *et al*. (2012) analysed mainly German, Austrian and Swiss post-occupancy evaluation research results on nearly zero-energy dwellings and undertook a survey of occupants of nearly zero-energy houses in the Netherlands. The study determined how various comfort parameters (such as winter thermal comfort, summer thermal comfort, indoor air quality and acoustics), information provision and control parameters are related to positive or negative end-user appraisal, finding that summer comfort design and the

quality of – and information about – heating and ventilation systems are critical factors which must be addressed to improve user satisfaction in nearly zero-energy dwellings (Mlecnik *et al.* 2012).

Yakubu (1996) presents a study of a user-experience survey about living in passive solar homes. It was carried out at the Energy Park located in the western part of Milton Keynes, UK. The survey focuses on the reality of living in passive solar homes as perceived or experienced by the occupant. It is hoped that the findings would come to bear on strategic passive solar design decisions that would address the improvement of the well-being of the occupant. The survey is aimed at assessing user satisfaction with the overall performance of their homes as well as a study of some of the problems that are believed to be common in passive solar housing. Results from the survey seem to indicate that the majority of those who buy passive solar homes are motivated to do so by a desire for thermal comfort at low cost. The building aesthetics is the second most important factor, showing that passive solar home lovers are also conscious of the quality of the architectural design. The overall performance of passive solar homes in this study, with regard to thermal and visual comfort, seems to be generally satisfactory. Statistical analysis showed some significant association between some important environmental design parameters.

Filippín *et al.* (2008) analyses the design, technology, thermal behaviour, and energy consumption of both a conventional and a refurbished dwelling located in a region with a temperate-cold climate in central Argentina. The results show the outstanding importance of introducing an energy-efficient refurbishment of conventional buildings to save energy and money. The thermal and energy behaviour can be improved by taking advantage of the thermo-physical properties of the materials used in walls and roofs.

A passive houses platform was established in 2002 to introduce the passive house concept in the Flanders Region, Belgium. Just four years later, demonstration projects and novel technologies are already available for the Benelux market, which swung the local market development by a factor four. Several passive houses are already inhabited. Within the framework of the European project 'Promotion of European Passive houses', these projects have been documented in English, Dutch and French. The paper by Mlecnik and Marrecau (2008) discusses design aspects, construction details, and technical information of example projects. The examples highlight the feasibility of the realisation of passive houses in the Low Countries.

Within the PASS-NET project a European wide Passive House database showing best practice buildings were built up (see Fig. 1.1). A good overview for stakeholders about the framework for passive house projects, the legal situation, support programmes etc were described for each PASS-NET country. To facilitate the awareness building and information about passive house

technology, a common basic training programme is being developed and translated into each national language.

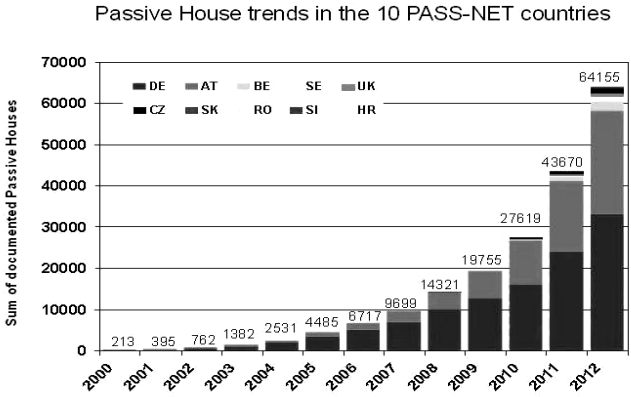


Fig. 1.1. Passive house trends in the 10 EU countries (Lang 2009)

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. Within the research project, two building prototypes were realized with unfired loam bricks (two-storey family houses with the Passive house Standard). One of the challenging steps was to implement a sufficient load bearing use of the unfired loam bricks, which would allow a realization of passive houses with nearly 100% unfired loam brick walls. The projects were completed in summer 2006. The evaluation results regarding the practicability of the scientific solutions were documented and first experiences of the house owners were collected (Paschoalique, Macho 2009).

German-born Katrin Klingenberg, founder of e-co lab, completed a 1.200 square foot home in Urbana, Ill., in 2003. Her goal was to demonstrate that stringent Passive house energy standards could be met in the severe climate of Central Illinois, USA. The project has succeeded, inspiring the ongoing construction and research efforts of e-co lab (*Construction Projects* 2003).

Macias *et al.* (2009) states that for Spanish climate, action should be taken to reduce energy demand for heating and cooling in residential buildings. The performance of a passive cooling system was developed as a part of design work

for the project of a low cost residential building. The passive cooling systems incorporate a solar chimney and precool the air by using the sanitary area of the building. The natural ventilation is enhanced with the help of the solar chimney and fresh air is cooled down by circulation within the sanitary area. The application of this system to the living rooms of a low cost residential building was evaluated and implemented. This cooling system incorporated to a residential building is the third prototype developed since 1991 by the designers. A model was developed to allow to predict the temperature of the air in the living room. The performance of the passive cooling system was evaluated based on the energy balance for a typical summer day.

Successful dissemination will in the long run depend on better matching of technical and planning concepts to the needs and expectations of users. The improvement of low energy house technologies has to be organised as a mutual learning process of component producers and users (users in a wide sense, i.e. professionals, companies, building societies, etc). Travelling through "science" and travelling through "experience": Architects and craftsmen between the study of the written sources and tacit knowledge. The paper by Valeriani (2007) addresses the question of the relationship between the intellectual work of the English architects importing (and partly adapting) designs that had been used in other countries, and the tacit knowledge element provided by the carpenters. There can be no doubt that on the English side, changes were made to the adopted techniques in order to adapt them to local needs. In particular, the carpenters were probably in charge of solving detail-problems (such as junctions and so on), and they will have achieved these solutions using pre-existing skills and techniques. Research done in this field shows that the introduction of the new building techniques to England was due to the efforts of the architect and not – as one would imagine – the carpenters. The evidence collected in buildings designed by Wren were taken to show the influence of the local carpenters' specific skills and technical knowledge on the imported Italian exemplars. In particular, the focus was on the assemblage methods and the carpentry marks (Valeriani 2007).

Pathirage *et al.* (2006) presented the concept of the knowledge worker and their tacit knowledge still lacks sufficient attention within construction industry, despite the fact that proper understanding and management of this resource is of immense importance for the achievement of better organisational performance.

Wang and Gwilliam (2009a) disscuses possible solutions for zero energy building design in UK. Simulation software (*EnergyPlus* and *TRNSYS16*) 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.

Comfort conditions and energy savings obtained using phase-change materials (PCMs) on a typical Portuguese family house, in summer, are analyzed for three different locations in the country: Interior-North (Bragança), center (Coimbra) and interior-South (Évora). Assessment of the effectiveness of PCM is based on the simulation results obtained using the "ESP-r" software package. Results show that comfort temperature conditions can be increased and energy needs for cooling can be reduced to roughly one half using PCM. Nighttime ambient temperature shows to be of major relevance, as PCM need to undergo the liquid-solid phase change during the night (Fernandes, Costa 2009).

In France, where a division by 4 of the greenhouse gases emissions is aimed from 1990 to 2050, technical solutions are studied in order to reduce energy consumption while providing a satisfactory thermal comfort level in buildings. A two-dwelling passive building has been carried out in Formerie (North-West of France), complying the “Passivhaus” standard. This building, not yet monitored, has been modeled using the dynamic simulation software COMFIE, which is dedicated to building eco-design. In order to account for the implemented ventilation system, including a heat recovery unit and an earth-to-air heat exchanger, a specific model has been developed and integrated to COMFIE as a new module (Thiers, Peuportier 2008).

The application of bioclimatic principles is a critical factor in reducing energy consumption and CO_2 emissions of the building sector. Tzikopoulos *et al.* (2005) develops 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 (Tzikopoulos *et al.* 2005).

In Sweden, 39% of energy use originates from the building sector, and this figure is increasing. Several attempts have been made to improve the energy use, for example low-energy houses, which are built with the aim of decreasing the use of energy, but still providing a good environment for the occupants. An energy simulation program, ESP-r, was used for simulation of the energy requirement and indoor climate in a well-insulated terraced house in Sweden (Karlsson, Moshfegh 2006). The building model was compared to measured values from the real object. A computational fluid dynamics (CFD)-model for one room was used to simulate and visualize the airflow and temperature pattern. Increased set-point temperature increases the power demand by about 200 kWh/8C. Thinner insulation increases the heat demand but decreases the demand for passive cooling by airing and deteriorates the indoor climate. Different types of windows affect both the energy demand and the indoor climate significantly. Load management was simulated by restriction on the heating possibilities and an economical comparison was made to investigate the advantage of such an operation (Karlsson, Moshfegh 2006).

Indian scientists 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. The results obtained in this work support the formation of low-energy structures, which is the present day need in the midst of high energy consuming structures. Model's predicted reduction in heat transfer and indoor air temperature fluctuation increase with increase in earthcontact of building structure. It is believed that the results presented in this study could serve as a useful reference for earth shelter buildings and would also be useful for further research on earth shelter buildings in India (Kumar *et al.* 2007).

The large windows on the south-oriented facade of a passive house strongly contribute to building space heating (Badescu, Staicovici 2006). These windows constitute the passive solar heating system. The integrated model, which includes the following subsystems: (1) solar thermal collectors, (2) a water storage tank, (3) a secondary water circuit, (4) a domestic hot water preparation system and (5) an air ventilation and heating system was implemented to Pirmasens Passive house (Rhineland Palatinate, Germany). The active solar heating system provides a smaller amount of heat than the heat provided by the

passive solar heating system. Almost all the solar energy collected is not used for space heating but to domestic hot water (DHW) preparation. It's revealed that on a yearly basis it is more advantageous to use vertical southoriented solar collectors instead of roof placed collectors (Badescu, Staicovici 2006).

Badescu (2007a) developed previous research on space heating in passive houses (PH). The results reported are based on a complex theoretical model used to simulate the heating system operation in Pirmasens PH (Rhineland Palatinate, Germany). The economic feasibility of different active space heating systems based on ground thermal energy utilization was studied. Both the heating and cooling potentials of the system under real climatic conditions were investigated. On medium- and long-time operation (i.e. longer than 3–10 years), a ground-source heat pump (GSHP) configuration proves to be the best economical solution. The configuration based on a ground heat exchanger is also a better solution than conventional heating in case the operation time is longer than 20–30 years.

A simple and accurate ground heat exchanger model is developed by Badescu (2007b). The thermal behavior of the heat exchanger is modeled by means of a numerical transient bi-dimensional approach. Several slices in the direction of the drainage are considered. Each slice is connected with its neighbors by thermal energy balance at the level of both the ground and the pipe. The boundary condition at ground surface derives from an energy balance equation involving the convective energy exchange between air and soil, the solar radiation absorbed by the ground surface, the latent heat flux due to evaporation at the ground surface as well the long-wave radiation. This approach allows to computing the ground temperature profile at the surface and at various depths.

In many EU countries, the normative requirements for thermal characteristics of roofs are associated only with rating the heat losses through the roofs during the heating period. The problem of overheated premises under the light-weight ventilated roofs, covered with steel sheets, arises in the summer time. During this period of the year, because of the intensive solar radiation and high air temperature, the steel roof coatings heat up during the day and cause additional heat inflows to the premises. One of the most effective means to reduce the additional radiative heat flow from the interior surfaces of the roof coating into the attic is to install radiant barriers with low emissivity coefficient into the roof construction. The experimental research has shown that having heat reflective coatings with low emissivity coefficient ($\varepsilon = 0.09$) installed on the exterior surface of the thermal insulation layer of the ventilated roofs with steel coatings, the heat flow from the roof coating through the roof construction into the interior premises can be reduced on the daily average of 23–25% in the summer time (Venckus *et al.* 2010). On the grounds of the obtained results,

Venckus *et al.* (2012) determined that a lower heat source power than the one determined according to the outdoor temperature of the coldest five day period can be used to meet the indoor microclimate requirements in a low energy building. In this way, the expenses of heating system installation are reduced and the operational efficiency of the heat source is increased.

For clients, construction contractors and precast producers alike, the Rapp Autark Haus® offers lucrative prospects due to its design and manufacture. The entire units are produced at the factory. The insulation layer is placed directly on the shuttering tables, and the concrete cast onto the insulation. This molding process results in savings in materials and work steps. Only the façade finishing (render, linings etc) still needs to be completed on the site (Rapp 2008).

In the project "Promotion of European Passive Houses" the scientists from the west of Europe tried to identify a typical solution for a heat load of 10 W/m² (including safety margins). In a first step, this was done by adapting the insulation level of the opaque parts of the shell; if that was not sufficient, the window quality and size were also changed (Schnieders 2006).

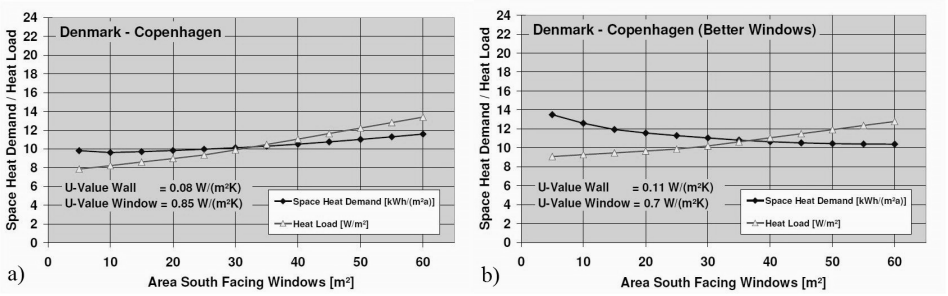


Fig. 1.2. Comparison of the thermal transmittance rate U of walls in Denmark: a) Windows; b) Better Windows

Design temperatures in Vienna are therefore lower than in Germany, and more insulation is needed to achieve a heat load of 10 W/m². The standard Passive house windows are still sufficient (Schnieders 2006).

The climate data set for Copenhagen that was used (TRY Copenhagen) contains a cold spell with temperatures below -20 °C (see Fig. 1.2). This appears rather exceptional if compared to the typical climate on the German coast of the Baltic Sea with -15 °C. The low temperature during a short period results in relatively low annual space heat requirements at a heat load of 10 W/m². Using the typical window quality, very good insulation of the walls, etc, is required. In Copenhagen, less solar radiation is available during the heating season than in Germany. Therefore, with the same window quality, larger windows lead to a larger space heat demand. If, on the contrary, windows with U = 0.7 W/(m²K)

instead of 0.85 W/(m²K) are used, increasing the area of the south facing windows results in a smaller annual space heat demand. Better windows allow for a substantial reduction in the insulation level of the opaque envelope elements, too. This example shows that for successfully planning a Passive house, a calculation that takes all these effects into account is highly recommendable - simple rules of thumb will not do (Schnieders 2006).

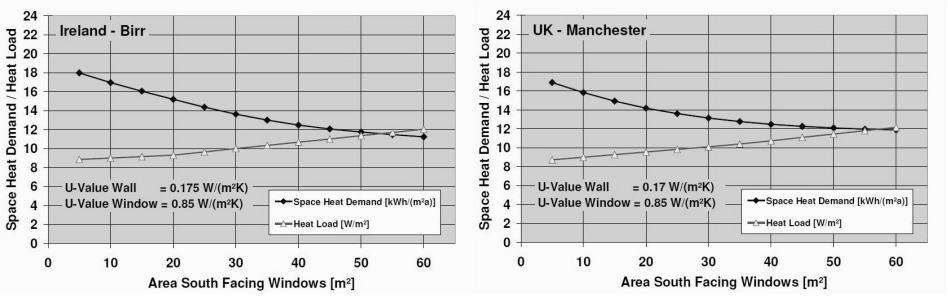


Fig. 1.3. Comparison of the thermal transmittance rate U of walls in Irish and UK

Measured data from a year which was claimed to be typical for Birr were used. The Irish climate (see Fig. 1.3), like others which are strongly influenced by the gulf stream and the thermal buffer effect of the sea, is a lot milder than the German one. Solar radiation levels in winter, on the other hand, are comparable to Germany. Therefore, a lot less insulation than in Germany is required. Under favourable boundary conditions, south facing windows may achieve high net solar gains (Schnieders 2006).

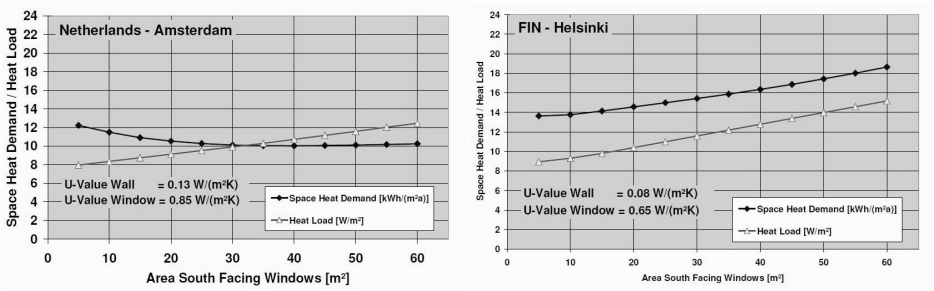


Fig. 1.4. Comparison of the thermal transmittance rate U of walls in Finland and Netherlands

Climate conditions in the UK (TRY Manchester) are very similar to Ireland (see Fig. 1.3). The results for Manchester are therefore nearly identical to those of Birr (Schnieders 2006).

Amsterdam data were taken from ASHRAE 2001 (List... 2011). Insulation requirements turned (see Fig. 1.4) out to be quite comparable to the German reference case (Schnieders 2006).

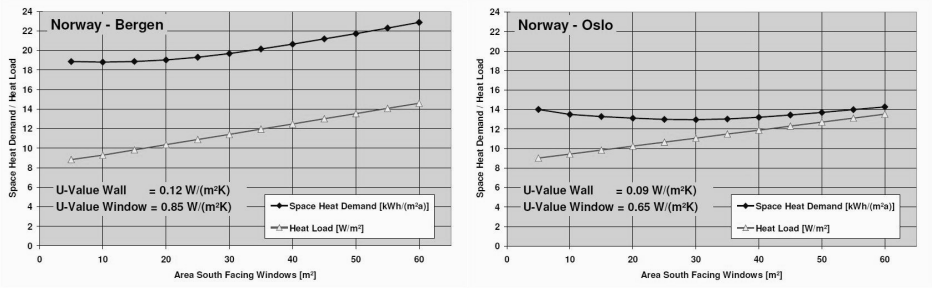


Fig. 1.5. Comparison of the thermal transmittance rate U of walls in Norway (Norway – Bergen and Norway – Oslo)

The IWEC data for Brussels are very similar to those for Amsterdam. In general, there is a little less solar radiation; depending on window size, the space heat demand in Brussels may be up to 20% higher than in Amsterdam (Schnieders 2006).

For Norway, two "Representative Design Years for Solar Energy Applications" from IEA-SHCP, Task 9, were available. The first location, Bergen, is renowned for its high amounts of annual precipitation. Being situated at the North Sea, the climate is a lot milder than at other locations at the same latitude. Insulation levels may therefore be chosen similar to Germany. Due to the low solar radiation, though, small windows are advantageous for minimizing the space heat demand. In Oslo, although it may be reached by large, seaworthy vessels, the climate is substantially less maritime than in Bergen. Minimum temperatures during the night may be as low as -25 °C (see Fig. 1.5), but there is more solar radiation available than in Bergen. In order to limit the heat load to 10 W/m², very good insulation and further optimized windows are required (Schnieders 2006).

Helsinki (IWEC data) combines the difficulties of Oslo and Bergen: Minimum temperatures are comparable to Oslo, but radiation levels are close to zero in December and January. In order to build Passive houses, extremely good insulation, small, highly insulated windows and a compact building shell will be required unless better components, especially better windows, can be made available (Schnieders 2006).

In Lithuania to achieve more rapid diffusion and further development of innovative residential buildings, measures from the federal and provincial governments have to be taken. Regulations prescribing significantly higher insulation standards are expected to be very effective and to play a key role in

triggering other technologies whose acceptance and economic application depends on an optimised building envelope. The development of certified standardised single components and complete solutions, for which producers can give warranty, will also speed up the diffusion of innovative buildings. Individual options for the supply of remaining heat demand which fulfil the criteria of sustainability on the one hand, and support a high degree of identification for the user on the other, should be offered.

In Lithuania the way residential buildings are subsidised has to be re-thought. Subsidies should be based on a least cost strategy, with minimisation of energy consumption and a sustainable supply of remaining heat demand as the major objectives and be harmonised on a national level. Subsidies should only be given if independent information centres, whose task is to supply and spread information offensively (which still have to be created), are already integrated in the planning stage of a building. The ecological relevance of tax systems has to be improved. The inclusion of external costs in the price of fossil energy carriers enables an objective economic comparison between fossil and renewable sources of energy. Energy savings must have an effect on the energy bill of a resident, and must not be weakened by collective billing arrangements in centralised systems. A high degree of personal identification with the building should be one of the major goals when dwellings are allocated within the scope of “social housing”. This can be achieved if the potential future resident may have the choice between an apartment in the innovative building and another apartment in a more “conventional” building.

1.2. Political, economic, socio-cultural and technoligical aspects in the construction of passive houses around the world

Soares *et al.* (2013) aims to explore how and where phase change materials (PCMs) are used in passive latent heat thermal energy storage (LHTES) systems, and to present an overview of how these construction solutions are related to building's energy performance. A survey on research trends are firstly presented followed by the discussion of some physical and theoretical considerations about the building and the potential of integrating PCMs in construction elements. The different types of PCMs and main criteria that govern their selection are reviewed, as well as the main methods to measure PCMs’ thermal properties, and the techniques to incorporate PCMs into building elements. The numerical modeling of heat transfer with phase-change and heat transfer enhanced techniques are discussed, followed by a review of several passive LHTES systems with PCMs. Studies on dynamic simulation of energy in buildings

(DSEB) incorporating PCMs are reviewed, mainly those supported by EnergyPlus, ESP-r and TRNSYS software tools. Lifecycle assessments, both environmental and economic are discussed. Review by Soares *et al.* (2013) shows that passive construction solutions with PCMs provide the potential for reducing energy consumption for heating and cooling due to the load reduction/shifting, and for increasing indoor thermal comfort due to the reduced indoor temperature fluctuations.

Danny *et al.* (2013) analyse buildings account for a significant proportion of the total energy and carbon emissions worldwide, and play an important role in formulating sustainable development strategies. There is a growing interest in ZEBs (zero energy buildings) in recent years. Several countries have adopted or considering establishing ZEBs as their future building energy targets to help alleviate the problems concerning the depletion of energy resources and the deterioration of the environment. Broadly speaking, ZEBs involve two design strategies – minimizing the need for energy use in buildings (especially for heating and cooling) through EEMs (energy-efficient measures) and adopting RETs (renewable energy and other technologies) to meet the remaining energy needs. This paper reviews the works related to these two strategies. EEMs include building envelopes, internal conditions, and building services systems; RETs cover photovoltaic/building-integrated photovoltaic, wind turbines, solar thermal (solar water heaters), heat pumps, and district heating and cooling. Issues pertaining to sustainable development implications and further research work required are also highlighted. These include life-cycle cost and environmental impacts, climate change and social policy issues.

In Qatar and the MENA region built environment has a direct impact on the Gulf Region natural environment, the economy and human health. Buildings have to respond to local climate and site conditions to maximize building users' comfort and health while minimizing energy use. Global Sustainability Assessment System (GSAS) developed a simplified, standalone, building energy standard to support Qatar's and the MENA region building energy ratings. Air conditioning counts for more than 60% of the electricity consumption in GCC countries. Consequently, GSAS limited the maximum annual cooling demand for new-build housing compliance in Qatar to 121 kWh/m^2. High rated energy-efficient houses must call for 72 kWh/m^2 or less. GSAS targets raised the need for innovative passive design technologies to reduce the cooling demand in hot humid climates. A prototype house was constructed to test new technologies and variant insulation techniques, such as dynamic insulation. The house has two operation modes, the static mode and the active mode (Elsarrag, Alhorr 2012).

Elsarrag and Alhorr (2012) presents the Passive-House pilot project construction details and the monitoring results within the tested period. The study compares the annual cooling demand from the simplified GSAS Energy

Calculator model and the detailed Dynamic Simulation Model (DSM). Neither model can handle the thermodynamic and fluid dynamic processes of the active insulation. An independent model is used to calculate the heat-transfer coefficient of the dynamically insulated walls, validated experimentally and then coupled with the energy models. The discrepancies in the predicted annual cooling demand between the simplified and detailed models did not exceed 15% for both static and dynamic operations of the Passive-House. Energy assessors can use GSAS Energy Calculator to predict the annual cooling demand with more confidence to demonstrate buildings compliance. Energy models should account for in-use factors to allow for differences in practical installation and performance compared to the laboratory test conditions for selected systems and technologies, which require field trials.

Cellura *et al.* (2013) presents an energy and environmental extended input–output model combined with the life cycle assessment, applied to assess the energy and environmental benefits arising from the Italian policy of tax deduction for energy retrofit actions of buildings. The study allowed to assess the advantages due to the above policy, taking into account both direct and indirect energy saving and avoided CO_2 emissions obtained with the retrofit actions and indirect energy consumption and related CO_2 emissions due to the realization of the above actions. Moreover, the authors defined an original model to assess the indirect rebound effect caused by the energy saving actions. The obtained results showed that a reliable evaluation of the benefits arising from sustainable policies strongly depends on the indirect rate of the energy consumption and energy saving, that in the examined case study has the same order of magnitude of the direct one, and on the rebound effect, that can partially avoid the obtained benefits. The study represents one of the first Italian experiences aimed at assessing the effectiveness of sustainable production and consumption strategies. It can be used to support decision makers in the selection of policies aimed at reducing energy and environmental impacts caused by final consumptions.

Van den Bergh (2013) indicates that there is much hope that environmental innovation and green technologies will remove the threat of climate change. This paper offers a critical perspective on the role of technological innovation to solving environmental problems. To this end it will synthesize empirical insights about structural economic change, energy and environmental rebound, the energy return on energy investment of renewable energy technologies, and potential crowding out effects of climate policy. Distinguishing features of green technologies, and the diversity and motives of green innovators are briefly discussed to examine opportunities for environmental innovation. The desirable combination of environmental and innovation policies to assure effective environmental innovation is assessed. An extended argument is offered in favor

of environmental (CO_2) pricing to make sure that innovation effectively contributes to environmental aims. The timing of policy also receives attention.

In Turkia energy conservation is an increasingly important issue for the residential sector (Kaynakli 2012). Therefore, attention towards the thermal performance of building materials, particularly thermal insulation systems for buildings, has grown in recent years. In this study, a literature review on determining the optimum thickness of the thermal insulation material in a building envelope and its effect on energy consumption was carried out. The results, the optimization procedures and the economic analysis methods used in the studies were presented comparatively. Additionally, a practical application on optimizing the insulation thickness was performed, and the effective parameters on the optimum value were investigated.

Murphy (2012) presents building regulations form one part of a policy response to energy security and climate change in jurisdictions across the world. The building sector, with responsibility for approximately 40% of global energy use, is a likely target for regulatory intervention. Households, considered by some to be relatively innocuous in terms of environmental impact, are responsible for the majority of the sector's energy use. As a result, many jurisdictions are developing building regulations as more sophisticated mechanisms to reduce unsustainable energy consumption. These developments, if successful, may alter our understanding of conventional houses and the role of occupants as passive energy consumers.

Parker (2009) presents measured annual performance data from a dozen recent-vintage very low energy homes in North America. Many of the designs combine greater energy efficiency with solar electric photovoltaic power in an attempt to create Zero Energy Homes (ZEH). Also paper provide measured data from the first home constructed to the German Passivhaus standard in the United States. Several projects either exceeded or come very close to true net zero energy when evaluated over a year.

According to Georges *et al.* (2012), in order to reduce the energy consumption of the building stock, a major trend is to drastically reduce the space-heating (SH) needs by improving the thermal performance of the envelope. In general, this measure is combined with efficient heating systems to minimize the delivered energy and greenhouse gas emissions. Nevertheless, these better systems are often more expensive so that the extra-investment could be hardly recovered for small-scale energy consumption. Georges *et al.* (2012) show how equilibria between cost-effectiveness and environmental performance of heating systems are changed when small SH needs are considered (i.e. for passive and low-energy houses). The scope is limited to new single-family dwellings. Furthermore, the passive house standard provides means of simplifying the SH by using the ventilation air: the idea is that savings should

counterbalance the extra-investment in super-insulation. In theory, a new global economic optimum is generated at the passive house level. The second objective of this work was to study which conditions could lead to this new optimum. Only a detached-house typology is investigated to address this last issue. Regarding methodology, all the investigations are done considering the Belgian context. Energy and environmental performance is evaluated using a method that complies with the EN-15603 and EN-15316 standards (Georges *et al.* 2012).

Berggren *et al.* (2013) reveal that the basic concept of a Net Zero Energy Building (Net ZEB) is that on-site renewable energy generation covers the annual energy load. The main objective of this study is to analyse the increase of embodied energy compared to the decrease of the energy use related to building operation; partly by a literature review, partly by detailed analysis of eleven case studies; taking the step from a low energy building to a Net ZEB. The literature review shows that the metric of evaluation, assumed life-span, boundary conditions, age of database and the origin of database differ in different studies and influence the result of embodied energy. The relationship between embodied energy and life cycle energy use is almost linear for all cases studied herein. During the last two decades, embodied energy in new buildings has decreased slightly. However, the relative share of embodied energy related to life cycle energy use has increased. The detailed life cycle energy analysis show that taking the step from a low energy building to a Net ZEB results in a small increase of the embodied energy. However, the energy savings achieved in the annual operating energy balance clearly exceed the increase in embodied energy.

In France energy efficient building are designed to minimize heating, cooling and lighting energy loads, so that attention is now paid on the energy consumption related to inhabitants (e.g. use of appliances) and life cycle issues: fabrication of materials, construction, maintenance, dismantling and waste treatment. In order to study these aspects, both in new construction and renovation projects, thermal simulation has been linked to life cycle assessment (Peuportier *et al.* 2013). Until now, such studies consider a conventional occupants' behaviour, or use monitoring results to adapt the model. The approach proposed in this paper complements life cycle assessment with a sensitivity study in order to account for the variability in real occupancy scenarios, but does not require monitoring results so that it can be performed during the design phase. Application of this method is illustrated by a case study regarding two attached passive houses built in France. The results show the essential influence of occupants on the performance, but varying the occupancy scenario does not modify the ranking between the compared alternatives. Checking the robustness of life cycle assessment results increases the relevance of this method as a design aid (Peuportier *et al.* 2013).

The passive house, along with models of its composite parts, has been developed globally. Simulation tools analyze its energy use, comfort, micro-climate, quality of life and aesthetics as well as its technical, economic, legal/regulatory, educational and innovative aspects. Meanwhile the social, cultural, ethical, psychological, emotional, religious and ethnic aspects operating over the course of the existence of a passive house are given minimal attention or are ignored entirely. However, all the aspects mentioned must be analyzed in an integrated manner during the time a passive house is in existence. Kaklauskas *et al.* (2012) implemented this goal while participated in two Intelligent Energy Europe programme projects the NorthPass and the IDES-EDU. The Passive house model for quantitative and qualitative analyses and its intelligent system was developed during the time of these projects. The model and intelligent system are briefly described in this article, which ends with a case study.

The study within the NorthPass project (*NorthPass Project*) examines the market situation of very low-energy houses in eight North-European countries, and suggests marketing approaches in each of these cases. Each country contributed to the study by providing general and also more specific information about the market situation in their countries and about successful cases in which energy efficient construction measures had already been implemented. The market situation was analysed with the help of PEST analysis, and new marketing approach was reached by defining strengths and opportunities in each country. The eight countries differ from each other to a large extent in terms of the political environment, state support, availability of low-energy houses and products needed for construction, environmental awareness and the level of knowledge. Therefore an individual proposal for a suitable marketing approach is needed in each country.

PEST analysis includes examining the macro-environment of the market which consists of political (and legal) forces, economic forces, socio-cultural forces, and technological forces (*NorthPass Project*).

The Political arena has a huge influence upon the regulation of businesses, and the spending power of consumers and other businesses. Issues such as the stability of the political environment, laws regulating or taxing the business, government's position on marketing ethics, government's policy on the economy, government's view on culture and religion and its involvement in trading agreements should be considered (*NorthPass Project*).

Economic factors include, among others, interest rates, the level of inflation, employment level per capita, long-term prospects for the economy and GDP.

How socio-cultural forces influence the market, depends highly on the country. Therefore, it might be important to consider issues such as dominant region, attitudes towards foreign products, the impact of language on diffusion

of products, the time available for leisure, the roles of men and women within the society, the age distribution and wealth of population and the attitudes towards green issues (*NorthPass Project*).

Examining the fourth factor, technological factor, means paying attention to the possibilities of the technology for cheaper and better production, whether the technologies do offer consumers and businesses more innovative products and services, how the distribution of some items have been changed by new technologies and if technology offer companies a new way to communicate with consumers (*PEST Analysis*).

This PEST country analysis report on Lithuania provides a holistic view of the country, with insightful analysis of current and future issues, supplemented with relevant quantitative data to support trend analysis (see Table 1.1).

Table 1.1. A summary of the PEST-analysis of the Lithuanian low-energy housing market macro-environment (NorthPass Project)

Political environment: • Lithuanian Housing Strategy aims at renovating 70% of the multi-apartment buildings by 2020. • The National Energy Efficiency Programme 2006–2010. • Programme for the Modernization of Multi-Family Buildings.
Economic Environment: • Lithuania has suffered from the global economic crisis (a high debt rate). • 97% of the housing stock is privately owned, 60% of it are in multi-family buildings. • Only a few low-energy houses exist.
Social Environment: • Almost one fourth of the population are pensioners. • Citizens in Vilnius and other cities have the highest purchasing power. • 66% of the population live in multi-apartment buildings (constructed • between 1960–1990) of which several thousands are in need for renovation for better energy efficiency. • 68% of the population live in urban areas. • Demand for single-family houses and semi-detached houses in suburbs will grow. • Lack of data, information and knowledge.
Technological Environment: • The Vilnius city housing renovation programme has illustrated the benefits of a renovated house.

1.3. Global practice related to passive houses and practical use of the available knowledge

Two German researchers conducted a research incorporating the CEPHEUS project results (Schnieders, Hermelink 2006). The results included the remarks provided by passive house occupants, the comfort parameters and other details. The researchers propose and present the project with their recommendations for users (Schnieders, Hermelink 2006):

1. "Basic needs" should always be considered in the design of any house type. Especially in passive houses for tenants these basic needs like "easy accessible, sufficient space for prams and bicycles" or "cool storerooms" have a considerable impact on satisfaction and acceptance.

2. There should also be a minimal ventilation for the staircase. Coming from their well ventilated flats, some tenants were disturbed by stale air in the staircase.

3. In rare cases there was disturbance from odours from make-up air. Intense investigations showed that under unfavourable wind conditions there was a short circuit between the openings for exhaust air and make-up air. This has to be avoided by arranging these openings in a way that avoids short circuits. In the project this enhancement could be realised by easy technical changes.

4. It has been mentioned already that people had problems to understand the "maximum ventilation" switch. The easiest solution is another switch in the bathroom/WC.

5. The exchange rate of the indoor air should be measured after the installation of the ventilation system. Unwanted high ventilation rates should be avoided to provide for agreeable humidity.

6. There should be apro mpt or a display indicating the failure of components like ventilators. Tenants do not care as much about the devices' proper functioning as owners do.

7. It should be absolutely clear which doors have to be closed to avoid unnecessary heat losses. In building 2 the inner door of the porch was designed to provide for atight building. Unfortunately the porch was used extensively for parking prams and bicycles. Therefore the inner door quite often stood open. As a result, all doors and cellar windows were equipped with small signs saying that in winter all doors and windows should be kept closed.

8. Written information about the handling of the heating and ventilation system only yielded moderate understanding. Therefore we strongly recommend that a qualified person should explain and demonstrate the handling of the system, e.g. change of filters, as soon as a tenant moves in.

9. A clue to the tenants' appreciation of extremely low heating costs is an easily understandable consumption bill. Although in each flat meters for energy

used for space heating had been installed, most of the tenants could not discern which of the various figures on the bill really indicated the cost for space heating. An interviewer, qualified in engineering, needed 20 min to understand the bill that was presented to him by a disenchanted tenant.

10. At the beginning, the housing company provided for acha nge of filters every 6 months. Intermediate cleaning of the filters turned out to be quite an effort with only little success. Now filters are changed every 3 months.

11. Components like fans, heat exchangers, and switches are not of high enough quality. Technical failures like broken fans, leakages in heat exchangers and failure of switches may trigger dissatisfaction with the whole passive house, although these components are not specific to passive houses. Just because tenants may need some time to perceive a failure, high quality standards taken for granted in other industrial branches should be met soon.

Considering the tendencies of energy production and price, it is becoming urgent to reduce energy consumption in buildings (Venckus *et al.*, 2010). The Kyoto protocol binded the developed countries to reduce the greenhouse gas emissions at least by 5% by 2008–2012 in order to tackle global warming and climate change. Some of the measures of the governments to achieve this goal are to promote new buildings construction and to retrofit existing buildings while satisfying low energy criteria. This means improving energy efficiency of buildings and energy systems, developing sustainable building concepts and promoting renewable energy sources.

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. Chlela *et al.* (2009) sets 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.

In Europe it can be noted that electricity has the highest conversion factor (meaning highest CO_2 emission per amount of energy), while district heating and gas, for example, have much lower conversion factors (Energy Saving Potential 2006). This means that savings in electricity use will result in much greater avoided emissions than savings in district heating. As this example illustrates, the energy sources used in a passive house (which differs per country) can have a large impact on the resulting emissions. As part of "Promotion of European Passive Houses" project, a method for determining the energy saving potential on national level has been developed. The energy saving potential on national level of participated countries are given below (Energy Saving Potential 2006):

- Austria. The current primary energy use of the typical new dwelling and the average existing household is relatively high in Austria. A passive houses uses around a factor 10 less for space heating than existing dwellings, resulting in a high energy saving potential for the passive houses, mostly in gas, oil and electricity.
- Belgium. The current energy use of the typical new dwelling and the average existing household is relatively high in Belgium. A passive house uses around a factor 10 less for space heating than existing dwellings, resulting in a high energy saving potential for the passive house.
- Denmark shows an average CO_2 reduction per dwelling of 1475 kg per new passive houses and 2931 kg per refurbished passive houses. Compared to typical new dwellings savings are mostly in electricity due to reduction in space heating and household appliances. Compared to existing dwellings savings are spread over more energy sources: electricity, district heating, gas and oil.
- Due to climate restrictions, the passive house in Finland, has an annual space heating energy demand of 40 kWh/m^2 instead of 15 kWh/m^2. Finland shows a CO_2 reduction of 182 and 406 kg for new and refurbished passive houses respectively. The absolute CO_2 reduction for Finland is relatively low, due to relatively high energy uses for the passive house (owing to climate). The passive house in Finland however still saves about 55% of the energy use for an existing dwelling. The fact that most reduction is achieved for district heating, which has a low CO_2 conversion factor (while electricity has a more significant impact on the amount of CO_2 emissions), causes the avoided CO_2 emissions through passive houses in Finland to be lower. Moreover, even electricity in Finland shows relatively low CO_2 emissions compared to other countries, as shown in Figure 1, which also results in fewer avoided CO_2 emissions.
- The primary energy use of a passive house in Germany is only about 28% of that of an existing dwelling. The CO_2 reduction per passive house in Germany is high, 2140 and 4226 kg for new and refurbished passive houses respectively. For a new passive house most CO_2 reduction is due to large electricity savings for household appliances (~50%) and space heating (~80%). Compared to existing dwellings, passive house savings are mostly in gas, oil (space heating ~90%) and electricity savings (household appliances ~50%).
- Ireland. The Irish existing dwellings show high energy uses. By realizing passive houses much energy savings can be reached.
- Norway. The total primary energy use of a passive house in Norway is 32% of that of an existing dwelling, and the energy use for space heating is 7% of that of an existing dwelling. Compared to a typical new dwelling, a passive house shows a total primary energy use of 41% and a energy use for space heating of 10%.

- United Kingdom. The total primary energy use of a passive house is 32% of that of an existing dwelling. Compared to a typical new dwelling, a passive house in the UK shows a total primary energy use of 41% and an energy use for space heating of 23%. In both cases a reduction of energy use for domestic hot water of 50% is expected.

1.4. Decision making models and methods

A thorough passive house evaluation is quite difficult to undertake, because a building and its environment are complex systems (technical, technological, ecological, social, comfort, esthetical, etc), where all subsystems influence the total efficiency performance and where the interdependence between sub-systems play a significant role. Many decision making models and methods (cost-benefit analysis (Goodacre *et al.* 2002), multiple criteria analysis (Brandt, Rasmussen 2002), the lattice method for global optimization (Saporito *et al.* 2001), predict a building's habitability index (Kusuda 2001) and energy rating systems for existing houses (Zmeureanu *et al.* 1999), etc) have been developed in the world for solving the above-mentioned and other problems. Many multiple criteria decision making (MCDM) or multiple criteria decision analysis (MCDA) methods have been developed in the world for solving the above-mentioned and other problems as follows: AHP method (Kablan 2004; Nigim *et al.* 2004; Jaber *et al.* 2008; Alanne *et al.* 2007), COPRAS (Kaklauskas *et al.* 2005, 2006), Data envelopment analysis, Decision EXpert, Disaggregation approach (Diakoulaki *et al.* 1999), Displaced Ideal (Mirasgedis, Diakoulaki 1997), Dominance-based rough set approach, ELECTRE (Georgopoulou *et al.* 1997; Beccali *et al.* 1998, 2003; Thiel, Mroz 2001), Evidential reasoning approach, Fuzzy sets (Beccali *et al.* 1998; Cavallaro, Ciraolo 2005; Gamboa, Munda 2007; Jaber *et al.* 2008; Alanne *et al.* 2007), Genetic algorithm (Juan *et al.* 2009; Wright *et al.* 2002), Goal programming, Grey relational analysis, Information deficiency method (Afgan, Carvalho 2002), Inner product of vectors, MACBETH, Multi-attribute-utility analysis (Renn 2003), PAPRIKA, PROMETHEE (Georgopoulou *et al.* 1998; Goumas *et al.* 1999; Haralambopoulos, Polatidis 2003; Cavallaro, Ciraolo 2005), SIR method, TOPSIS, Value analysis, Value engineering, Value tree method (Renn 2003), VIKOR, Weighted product model, Weighted sum model, PAIRS (Salo, Hämäläinen 1992).

The aforesaid methods were used to solve various problems of energy-efficient built environment:

- ELECTRE (Georgopoulou *et al.* 1997; Beccali *et al.* 1998, 2003; Thiel, Mroz 2001): regional energy planning, evaluation of renewable energy options,

renewable energy diffusion strategies, renewable energy technologies, selecting a heating system for a historical building.

- Disaggregation Approach (UTADIS: Diakoulaki *et al*. 1999): energy analysis and policy making.
- Value tree method (Renn 2003): evaluation of energy scenarios, waste energy utilization.
- Multi-attribute utility analysis (Renn 2003): selection of energy scenarios, waste energy utilization.
- PROMETHEE (Georgopoulou *et al*. 1998; Goumas *et al*. 1999; Haralambopoulos, Polatidis 2003; Cavallaro, Ciraolo 2005): promotion, planning and assessment of renewable energy sources; geothermal and renewable energy projects; "scenarios" for geothermal resources; renewable energy plants.
- Fuzzy sets (Zadeh 1965) (Beccali *et al*. 1998; Cavallaro, Ciraolo 2005; Gamboa, Munda 2007; Jaber *et al*. 2008; Alanne *et al*. 2007): technologies of energy conversion and heating distribution, renewable energy diffusion strategies, wind energy plants, locating wind turbines.
- PAIRS (Salo, Hämäläinen 1992): residential heating systems and the handlinge of uncertainties related to the actual preferences of decision makers for type heating systems.
- Displaced Ideal (Mirasgedis, Diakoulaki 1997): electricity generation systems.
- Information deficiency method (Afgan, Carvalho 2002): new and renewable energy technologies (power plants).
- AHP (Saaty 2001) method (Kablan 2004; Nigim *et al*. 2004; Jaber *et al*. 2008; Alanne *et al*. 2007): evaluation of conventional and renewable energy sources for household heating, prioritisation of policy instruments, pre-feasibility ranking of alternative renewable energy sources.

Multiple criteria decision making (MCDM) is the most well known branch of decision making. It is a branch of a general class of Operations Research (or OR) models which deal with decision problems under the presence of a number of decision criteria. According to many authors MCDM is divided into Multi-Objective Decision Making (or MODM) and Multi-Attribute Decision Making (or MADM) (Triantaphyllou *et al*. 1998). Different authors have different names for the concept of Multi-Objective Decision Making (MODM) such as multiple criteria design, multiple objective mathematical programming, or multi-objective optimization. MODM methods (Diakaki *et al*. 2010; Asadi *et al*. 2012; Diakaki *et al*. 2008; Wright *et al*. 2002) and MADM methods (Gero *et al*. 1983; Jaggs, Palmar 2000; Flourentzou, Roulet 2002; Rey 2004; Kaklauskas *et al*. 2006; Allane 2004; Kim *et al*. 2009; Diakaki *et al*. 2010) are widely used in analyses of energy-efficient built environment.

MODM studies decision problems in which the decision space is continuous. A typical example is mathematical programming problems with multiple objective functions. The first reference to this problem, also known as the "vector-maximum" problem (Triantaphyllou *et al*. 1998). The alternatives in this class of problems are not explicitly known, they are either infinite and not countable or typically very large if countable. MODM methods sometimes using interactive computer methods to involve the analyst explicitly in the process also, directly seek to specify what the definition of the best option should be. The question is essentially one of identifying an optimal design for the option, guided by MODM methods. Almost always, the optimisation is subject to specific constraints, for example on cost or technical specification (Multi-criteria analysis 2009).

The problem faced by the decision maker is in fact a multi-objective optimization problem, characterized by the existence of multiple and competing objectives, the decision space consisting in a set of feasible solutions that are not predefined but are implicitly defined by a set of parameters and constraints that should be taken into account. Therefore, it is not necessary to enumerate the set of actions to be considered (Diakaki *et al*. 2010).

A number of MODM methods has been used to analyse different areas of energy-efficient built environment such as design of building envelopes (Diakaki *et al*. 2008), selection of heating systems (Wright *et al*. 2002), optimal thickness of insulation (Malckzewski 1999), retrofit actions aimed at minimizing energy use in a cost-effective manner (Asadi *et al*. 2012), and improving energy efficiency in buildings (Diakaki *et al*. 2010).

Multi-Attribute Decision Making (MADM) methods often have alternative names, too (e.g. multiple-criteria evaluation).

There are many ways one can classify MADM methods. One way is to classify them according to the type of the data they use. That is, we have deterministic, stochastic, or fuzzy MADM methods (for an overview of fuzzy MADM methods (Chen, Hwang 1992). However, there may be situations which involve combinations of all the above (such as stochastic and fuzzy data) data types. Another way of classifying MADM methods is according to the number of decision makers involved in the decision process. Hence, we have decision maker MADM methods and group decision making MADM (Triantaphyllou *et al*. 1998).

MADM concentrates on problems with discrete decision spaces. In these problems the set of decision alternatives has been predetermined (Triantaphyllou *et al.* 1998). In MADM problems with a finite number of options, each of which is assessed in terms of a given number of criteria. For each option, with respect to each criterion, this performance information needs to be collected. Most decisions concern choices between a finite number of options, the details of

which have already been predetermined before they are subject to MADM. It is concerned simply to assess the strengths and weaknesses of options as they stand and find the best alternative (a set of good alternatives) for a decision maker (Multi-criteria analysis 2009). In a number of countries, scientists used MADM methods to solve miscellaneous problems of energy-efficient built environment:

- local energy systems involving several energy resources (Løken 2007);
- selection process (Malckzewski 1999);
- selecting a heating system for a historical building (Thiel, Mroz 2001);
- design of building envelope and refurbishment problems; selecting contractors for public buildings (Kaklauskas *et al*. 2005; Kaklauskas *et al*. 2006);
- evaluation of conventional and renewable energy sources for household heating (Jaber *et al*. 2008; Alanne *et al*. 2007);
- energy conversion and heating distribution technologies (Nagesha, Balachandra 2006);
- residential heating systems and the handlinge of uncertainties related to the actual preferences of decision makers for type heating systems (Salo, Hämäläinen 1992);
- building design (Gero *et al*. 1983);
- evaluation of retrofitting scenarios (Jaggs, Palmar 2000; Flourentzou, Roulet 2002; Rey 2004);
- multivariate design and multiple criteria analysis for building retrofitting (Kaklauskas *et al*. 2005, 2006);
- selection of the most feasible retrofit actions in the conceptual phase of a retrofit project (Allane 2004);
- housing condition assessment to suggest optimal retrofit actions considering the trade-off between cost and quality (Juan *et al*. 2009).

A few brief examples follow, as a quick illustration of the aforementioned MCDM methods applied in some areas of energy-efficient built environment.

Diakaki *et al*. (2010) investigated the feasibility of applying multi-objective optimization techniques to the problem of improving energy efficiency in buildings, considering a simplified model for building thermal simulation.

Due to growing limitations on land use and awareness of sustainability concerns, the building retrofit market has faced increasing opportunities worldwide. Several technological/constructive options are available to improve energy efficiency and indoor environmental quality in buildings. The identification of the most appropriate retrofitting options is a topic of outstanding importance given the potential costs and impacts involved (Asadi *et al*. 2012). Asadi *et al*. (2012) present a multi-objective optimization model and method to assist stakeholders in the definition of intervention measures aimed at minimizing the energy use in the building in a cost effective manner, while

satisfying the occupant needs and requirements. An existing house needing refurbishment is taken as a case study to demonstrate the feasibility of the proposed multi-objective model in a real-world situation. The results corroborate the practicability of this approach and highlight potential problems that may arise (Asadi *et al*. 2012).

Coherent and efficient retrofit scenarios are commonly built on the basis of the knowledge of the degradation state of the building and its obsolescence. The architect or building engineer prepares a list of refurbishment works required on the basis of the building audit, his experience and the available budget (Flourentzou, Roulet 2002). Flourentzou and Roulet (2002) describe a systematic method, based on multicriteria analysis and a constructivist approach, which helps an expert in designing retrofit scenarios. This approach includes several steps and follows an iterative process. The associated computer tool takes charge of tedious tasks such as calculating the associated costs, performing an energy balance, and checking for coherence between actions; and presents various viewpoints to the expert. It also helps the user in quickly creating various scenarios. The expert can then interact with this information and makes the decision for selecting the final scenario. This interactive approach brings together expert intuition and rational systematic verification (Flourentzou, Roulet 2002). Goodacre *et al.* (2002) use a cost-benefit analysis framework to assess the potential scale of some of the benefits from the comprehensive upgrading of heating and hot water energy's efficiency in the English building stock. Goodacre *et al.* (2002) attempted to evaluate the potential scale for societal costs that are associated with poor levels of domestic space heating and hot water energy's efficiency in the English building sector. The basic premise of this paper has been that an appraisal of these costs should be evaluated against a wider range of potential benefits, not only the direct benefits (micro-economic) and current government monetary appraisals.

The TOBUS method aims at offering a tool for selecting office building's upgrading solutions with respect to multiple criteria. One of the key elements to reach this goal is an assessment of the degree of physical degradation, extent of any degradation, extent of the necessary work to renovate the building and the costs (Brandt, Rasmussen 2002).

The energy performance in buildings is a complex function of the building's form and structure, heating system, occupancy pattern, operating schedules, and the external climatic conditions. To carry out a multi-parameter analysis for the optimization of the building's energy performance, the lattice method for globai optimization was used (Saporito *et al.* 2001).

Kusuda (2001) would likę to see the extension of the predicted building habitability index (PIHI) as an integrated evaluation criterion for a building's performance in which the simulated hourly energy consumption, comfort index

and system's economic factors were weighted (in accor-dance to specific application reąuirements) and were algebraically summed up to arrive at an index for determining the building's air conditioning needs. This PIHI concept can be extended to include other elements such as lighting, acoustics, moisture condensation, plumbing, etc.

According to (Zmeureanu *et al.* 1999), different approaches have been developed to evaluate the energy performance of houses, by using a simple index and they are known under the generic term of home energy rating systems (HERS) which can be classified in the following three main categories: the points system, which evaluates the energy performance of a house by giving points of performance or scores to each sub-system such as exterior walls, roof or heating system; the performance system, which assigns an index of performance in terms of the annual heating energy consumption or cost; and the awareness system, which recommends the totai annual and heating site's energy consumption, and the corresponding costs, in terms of the year the house was constructed and its climatic zone and the source of energy.

As one can see, the above-mentioned research has enabled the authors to sol ve a majority of problems in a complex way as far as a passive house is concerned. However, one of the weakest aspects of the above research was the formation and multiple criteria analysis of alternative variants of the whole building. The authors of thesis has developed a method of multivariant design and multiple criteria analysis of a passive house life cycle to tackle these problems.

1.5. Conclusions from Chapter 1

1. The analysis of technical, technological, management, cultural, social, political, economic and other aspects attitudes towards the construction of energy-efficient buildings in a number of countries leads to a conclusion that researchers look into these criteria mostly in isolation. Integration of all criteria into a single system would produce a more comprehensive description of a life cycle and components of a passive house.
2. Analysis of global research shows that existing passive house models do not permit for alternative multi-variant design of passive houses and multiple criteria analysis.
3. Analysis of projects and articles by different researchers suggests that they often focus on a single narrow field, such as assessments of the thermal transmittance rate of windows, walls or roofs, energy saving, etc. A passive houses knowledge model and the model’s solution methods should therefore be developed.

2

Development of a conceptual passive houses knowledge model

This chapter presents the conceptual passive houses knowledge model developed by the author and describes the model's elements in detail.

Four articles dealing with the topics discussed in this chapter were published (Kaklauskas *et al.* 2012; Rutė 2011; Matuliauskaitė *et al.* 2011; Rutė *et al.* 2010).

2.1. The concept of the passive houses knowledge model

The passive house, along with models of its composite parts, has been developed globally. Simulation tools analyze its energy use, comfort, micro-climate, quality of life and aesthetics as well as its technical, economic, legal/regulatory, educational and innovative aspects. Meanwhile the social, cultural, ethical, psychological, emotional, religious and ethnic aspects operating over the course of the existence of a passive house are given minimal attention or are ignored

entirely. However, all the aspects mentioned must be analyzed in an integrated manner during the time a passive house is in existence.

Various models of a passive house or its composite parts are being developed globally at the micro and macro levels. Such models include the ground heat exchanger (Badescu 2007a), heating system (Badescu 2007b), heating model of the active solar heating system (Badescu, Staicovici 2006), earth-contact building structures (Kumar 2007), a regression model of energy efficiency (Tzikopoulos *et al.* 2005), a computational fluid dynamics model (Karlsson, Moshfegh 2006), and others.

Furthermore scientists and practitioners from various countries are developing simulation tools for a passive house and its composite parts. Such simulation tools include dynamic simulation software (Thiers, Peuportier 2008), computer-aided design tool for passive solar systems (Yakubu 1996), simulation software for zero energy building design (Wang, Gwilliam 2009a), design of low energy buildings (Chlela *et al.* 2009), optimization tools BEopt and EGUSA (Parker 2009), and others.

The aforementioned models and simulation tools for passive houses and their composite parts analyze their energetic, technical, technological, economic, legal/regulatory, innovative and microclimatic aspects. However, the social, cultural, ethical, psychological, emotional, religious and ethnic aspects of the passive house during the process of its existence are generally paid no attention at all. It is necessary to analyze the life cycle of the passive house comprehensively on the basis of the aforementioned system of criteria to achieve an integrated examination of a passive house life cycle. The author developed the Passive houses model for quantitative and qualitative analyses and its decision support system while participating in two Intelligent Energy Europe Programme projects: “Promotion of the Passive house Concept to the North European Building Market” (NorthPass) and “Master and Post Graduate education and training in multidisciplinary teams implementing EPBD and beyond” (IDES-EDU). The developed intelligent system additionally provides opportunities for designing hundreds of thousands of passive house alternatives, selecting the most effective ones and establishing the market value of each alternative.

2.2. Passive houses knowledge model for quantitative and qualitative analyses

The Passive house model for quantitative and qualitative analyses was developed with the goal of integrating the energetic, technical, technological, economic, legal/regulatory, innovative, microclimatic, social, cultural, ethical,

psychological, religious, ethnic and other aspects of the process over the life of the passive house. This six stage model is presented in brief heretofore.

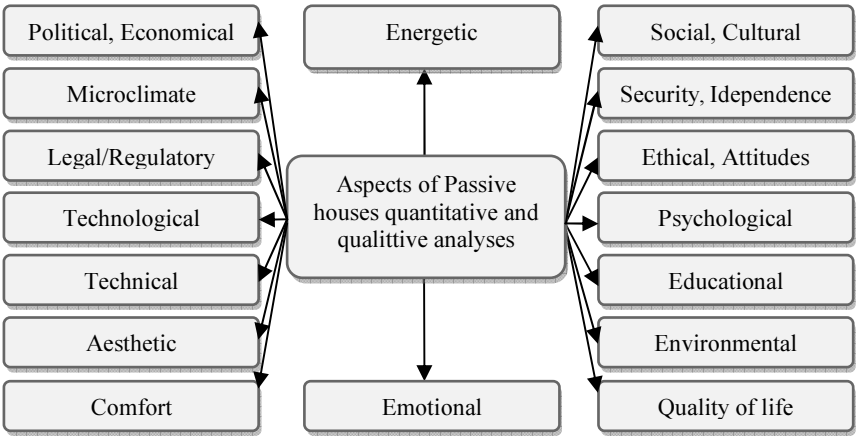


Fig. 2.1. Passive houses quantitative and qualitative analyses aspects

Stage I. Comparative description of the passive houses in developed countries and in Lithuania (by economic, legal/regulatory, technical, technological, organizational, managerial, quality of life, thermic, indoor quality, social, cultural, political, ethical, psychological and other aspects):

- Determining a system of criteria characterizing the efficiency of a passive houses by employing relevant literature and expert methods;
- Describing, per this system of criteria, the present state of the passive houses in developed countries and in Lithuania in conceptual (textual, graphical, numerical and such) and quantitative forms.

Stage II. Comparison and contrast of the passive houses in developed countries and in Lithuania:

- Identifying the global development trends (general regularities) of the passive houses;
- Identifying the differences in passive houses between developed countries and Lithuania;
- Determining the pluses and minuses of these differences for Lithuania;
- Determining the best practice for the passive houses in Lithuania as per actual conditions;
- Estimating the deviation between the knowledge stakeholders have of worldwide best practices and their practice-in-use.

Stage III. A multiple criteria analysis of the composite parts of a passive houses and selection of the most efficient life cycle for the project – henceforth

interlinking the received compatible and rational composite parts of a passive houses into a full passive houses project.

Stage IV. Development of certain general recommendations on how to improve the knowledge levels of stakeholders.

Stage V. Submission of certain recommendations to stakeholders including several particular alternatives for each general recommendation proposed.

Stage VI. Transformational learning and the redesign of mental and practical behavior.

A partial description of the two stages follow to illustrate the above-presented Model. These are Stage I – Passive houses socio-cultural aspects, self-expression values, environmentalism and global warming and Stage II – Lithuania's passive houses weaknesses.

2.3. Passive house socio-cultural aspects

Innovative construction of a passive houses serves the development and induction of new technologies in practice thereby laying the groundwork for economic growth. Furthermore, by offering innovative construction products, materials and services to a user, the user's viewpoint is broadened thus enhancing his/her good taste, and a need for a better quality of life forms. Nevertheless, a good deal of resistance and quite a few phobias that various socio-cultural factors stipulate are encountered at this point.

Ordinary people rely on cognitive shortcuts or heuristics to make sense of issues about which they have low levels of knowledge (Scheufele 2006), just as they do with many other political and scientific matters. These heuristics can include predispositional aspects, such as ideological beliefs or value systems (Kahan *et al.* 2008), as well as short-term frames of reference that the media or other sources of information provide (Scheufele, Lewenstein 2005). Recent research suggests that "religious filters" are an important heuristic for scientific issues in general (Ho *et al.* 2008).

Representatives of different cultures have ambiguous views towards the passive house. A great many socio-cultural factors influence such outlooks. The most important are social, cultural, ethnic, ethical, psychological, political, security, independence, attitudes, public support, religious/spiritual and environmental factors and trustworthiness. These are further presented in brief.

Social factors associate with people's income, social status, gender and other similar matters in life. A sufficient income lays the groundwork for the selection of an innovative passive houses when looking for more comfort, for a better quality home. The opposite is also true – a limited amount of funds forces selection of a traditional, more conservative home, because risk-taking is

undesirable. The level of the quality of life in Lithuania is not high by EU standards. Thus it is no surprise that Lithuanians are not especially interested in decisions regarding innovative passive houses.

Some USA organizations have measured public levels of concern by using various permutations of this question: How serious of a problem/threat is global warming? In a 1998 Mellman Group national poll, 70% of voters said global warming was a "very serious" or "somewhat serious" threat. By 2001 Time/CNN found that 76% thought global warming was a "very serious" or "somewhat serious" problem (Leiserowitz 2005). According to Dessai *et al.* (2004) lay public perceptions and interpretations of a dangerous climate change, however, are "based on psychological, social, moral, institutional and cultural processes". Public risk perceptions are influenced not only by scientific and technical descriptions of danger but also by a variety of psychological and social factors, including personal experience, affect and emotion, imagery, trust, values and worldviews (Slovic 2000).

A religious filter is more than a simple correlation between religiosity and attitudes toward science: it refers to a link between benefit perceptions and attitudes that varies depending on respondents' levels of religiosity (Brossard *et al.* 2009). Leiserowitz (2005) argues that religiosity is part of a package of cultural and social values that is often correlated with levels of skepticism about technological and environmental risks. According to Leiserowitz (2005) public attitudes about environmental and technological risks significantly correlate with a package of larger cultural criterion that include religiosity. Furthermore public risk perceptions are critical components of the sociopolitical context within which policymakers operate. Public opinion can fundamentally compel or constrain political, economic and social action to address particular risks. For example, public support or opposition to climate policies (e.g., treaties, regulations, taxes, subsidies) will be greatly influenced by public perceptions of the risks and dangers inherent in climate change (Leiserowitz 2005).

The book "The Protestant Ethic and The Spirit of Capitalism" is Weber's first brush with the concept of rationalization. His idea of modern capitalism as growing out of the religious pursuit of wealth meant a change to a rational means of existence, wealth. In essence then, Weber's "Spirit of Capitalism" is effectively and more broadly a Spirit of Rationalization. The Protestant work ethic is a concept in sociology, economics and history, attributable to the work of Max Weber. It is based upon the notion that the Calvinist emphasis on the necessity for hard work as a component of a person's calling and worldly success. It is argued that Protestants beginning with Martin Luther had reconceptualised worldly work as a duty which benefits both the individual and society as a whole. Thus, the Catholic idea of good works was transformed into an obligation to work diligently as a sign of grace. Whereas Catholicism teaches

that good works are required of Catholics to be saved (Wiki). Religious and cultural beliefs influence the outlook on the passive houses. People from highly religious countries, such as Lithuania, Poland or Ireland, are less likely to select a passive house. Meanwhile people from countries where religion is less meaningful, such as Belgium, the Netherlands and Scandinavian countries, make more favorable decisions regarding passive houses.

Developers, builders and their supply chains are in a position to drive innovation and economies of scale in energy efficiency and distributed energy technologies. The use of new approaches can have a demonstrator effect, not only to the house building industry but to tackling carbon emissions in existing homes and communities too. The zero carbon homes policy is designed to promote leadership in this important area. Potentially this process of innovation can help to bring about wider innovation in the house building industry too – transforming design, improving quality and changing the house building process through, for example, modern methods of construction.

Ethnic factors associate with the mentalities, comprehension of the priorities of material and spiritual values and the demands made for residential housing with consideration for long-standing national traditions of the various ethnic groups living within a country. The injustices and foreign occupations that Lithuania suffered over the course of history have made Lithuanians wary of innovations (including the newness of the passive house); however, at the same time, they are flexible coupled with conservative practicality.

Psychological factors associate with the features, inclinations and pleasures relevant to the psychological behavior of singular individuals and their groups that influence their life styles and their demands for residential housing. On their own accord, these aspects indicate the readiness of individuals to use modern construction materials and technologies as well as to accept the applicable risks. Lithuanians lived a long time within the enclosed sphere of the Soviet Union; thus they had no means to learn about and employ the latest technologies in construction and the standards of comfort in housing, such as those that the West deemed acceptable. This long-term isolation from the Western world contributed to the temperate view Lithuanians take regarding the innovations of the passive houses. However, this view has been changing, since Lithuania joined the EU and new opportunities opened up. Caution is more and more often aligned with the endeavor to achieve a better life style, which the application of new technologies in housing construction can assure.

Many academic debates about how citizens form attitudes about scientific issues boil down to a conflict between ideals and realities. There have been decades of research in social psychology, political science and risk communication suggesting that knowledge plays a marginal role, at best, in shaping people's opinions and attitudes about science and technology. In fact

many researchers have suggested that the way the media present an issue and people's value systems and predispositions play a much greater role in shaping citizens' attitudes toward new technologies. For example some critics of nanotechnology have referred to it as the "asbestos of tomorrow" alluding to the potential unknown and long-term risks connected with nanoparticles. This metaphor is a highly effective way of using asbestos to evoke an existing interpretive schema that many people share. More importantly the asbestos frame is difficult to counter since it refers to risks that will not be within awareness until decades down the road. However, if scientists want to have their views heard in public debates, they need to understand and use the tools that are available and appropriate for communicating effectively with different audiences (Scheufele 2006).

Although the aforementioned factors are important for every member of a socio-cultural community, each individual will ascribe his/her own priorities to them. On one hand, this indicates the level of the economic and social achievements of a community and the receptivity of its members for passive house innovations. On the other hand, the forms of untraditional activities and the methods and means for implementing decisions can cause phobias.

Innovation rarely comes from expected places. Thus low-carbon solutions can be expected to emerge from all parts of the economy – not just the established "energy" or "environment" sectors, both of which can be hidebound by traditional ways of thinking. The "disrupters" we studied included a leadership coach, a design student, a building services manager and a hill farmer. Environmentalists alone won't save the world. And real progress can be made when a series of innovations link together and set off a chain reaction. We need to think of innovation as "tipping points" and create policy that supports them. Where innovation is locked out of current systems, the government could create space for experimentation in low-carbon innovation zones. Local and regional decision makers could pledge carbon cuts and set a framework to achieve them. In return they could be given greater autonomy and scope for regulatory experimentation and a larger share of funding to find ways to involve local households, communities, businesses and the public sector in carbon reduction. In effect this would be a sort of low-carbon devolution creating the right conditions for radical change (Willis 2007).

The various components of the passive house approach can be classified under the following basic elements. The first three (superinsulation, heat recovery and passive solar gain) are crucial to the passive house concept. To fully minimize environmental impacts, however, the other two are necessary (electrical efficiency) or expedient (meeting remaining energy demand with renewables). In most cases, low energy consumption is not enough for owner-occupiers or tenants to move into a passive house. Such benefits are e.g. as

follows: prestige, wellness, comfort, environmental friendliness (Schnieders, Hermelink 2006). Compared to its neighbours, Lithuania's position in the Environmental Performance Index and the Environment Index is rather bad (see Table 2.1). The situation could be improved with more intense passive house development.

Table 2.1. Environmental performance and other indices

No.	Quality and Power Index	LT	Den	Sw	Fin
1.	Environmental Performance Index (2010)	37	32	4	12
2.	Quality of Life Index (2011)	30	11	3	7
3.	Health Index (2011)	34	25	10	21
4.	Education Index (2011)	25	18	23	1
5.	Wealth Index (2011)	44	16	6	19
6.	Environment Index (2011)	33	28	4	10
7.	Economy Index (2011)	75	25	17	31
8.	Technology Index (2011)	63	43	11	19

Source: Eurostat, (Emerson *et al.* 2010; Nation Ranking 2011)

According to Canadian Passive house Institute (Canadian Passive house Institute 2011), Passive house is the world's most ambitious and scientifically verified route to truly sustainable buildings, achieving 80–90% energy savings over conventional construction through radical conservation. Sustainable development is also important for the quality of life for the buildings' users. Modern technologies and innovative solutions used in the construction industry can significantly affect the comfort of apartments and offices, and thus the health of the occupants (Żelazna, Pawłowski 2011). Regarding high-tech sectors national averages, 17 out of the 32 observed countries registered values higher than the EU-27 average (3.7%) with over 5.0% in Denmark, Finland and Sweden. On the other range of the scale, the lowest national shares of high-tech sectors in total employment below 2.5% were registered in Greece, Cyprus, Latvia, Lithuania, Portugal, Romania and Turkey. Six European countries (Estonia, Cyprus, Latvia, Lithuania, Luxembourg and Malta) and Iceland are classified at NUTS level 1 (Science… 2011). Apparently, modern technologies and innovative solutions are not widely used in Lithuania, which evidently might have an effect on the comfort of apartments and offices, and thus the health of the occupants in passive house. It is a very important issue to Lithuania, the position of which in the Quality of Life Index and the Health Index is worse than that of other compared countries (see Table 2.1).

Complaints about the indoor environment indicate that certain health complaints are more prevalent with heat recovery ventilation systems. The occupancy level of dwellings is an indicator of health risk exposure as well (Hasselaar 2006). During a three week period different measurements in three of

the first passive houses projects in Netherlands were undertaken to define indoor air quality and thermal comfort. Results showed that in some cases ventilation was completely insufficient. Energy saving and sustainability is very important but not at the risk of endangering health of the occupants (Zeiler 2009). Smaller and well occupied passive houses are more at risk, with different indicators of potential health hazards (Hasselaar 2008). The situation with the average useful floor area per person is rather bad in Lithuania (24.9 m^2/person), while Denmark enjoys 51.4 m^2/person, Sweden 45.2 m^2/person and Finland 38.9 m^2/person. These trends seem to show that Lithuania will develop smaller and well occupied passive houses with potentially more health hazards. These are paramount issues to Lithuania, which globally ranks 34th in the Health Index (see Table 2.1), while Denmark (25th), Sweden (10th) and Finland (21th) enjoy impressive achievements in the area of health.

The Passive house standard can make a considerable contribution to overcoming the economic crisis. Above all, using this highly efficient standard will strengthen the regional economy. Local investments and generated turnovers will cause a boom independently from the global economic situation but with a sustainable effect on the worldwide climate (Energy Saving Potential 2010). These are important issues to Lithuania, which suffered from the crisis a great deal. In 2009 Lithuania's Real GDP Growth Rate (percentage change on previous year) dropped by as many as 14.8%.

As far as Lithuania, its construction processes and materials are concerned, different types of passive house will be determined by certain historical conditions. The types of passive house depended on different ethnic landscapes and regional traditions.

In Europe, a Passive house represents a level of superior comfort. The quiet interior environment features warm walls, fresh air, no drafts, reduced levels of dust and a surprising amount of natural light. Over 10.000 Passive houses Standard buildings have been constructed as of 2007 (US Housing… 2009).

In 1989 and 1990 there were many discussion in Lithuania how to achieve Lithuania's independence: should the priority be economic or political independence. Now the same discussion continues. Opponents argue that Lithuania joining the energy networks of Western and Northern Europe might mean more expensive electricity. In terms of energy, Lithuania in effect remains part of the USSR system. Lithuania seeks to become full member of Europe in terms of its values (energy, too), but is not so in terms of energy. This idea is foremost in construction of the LitPol Link and NordBalt interconnections. These interconnections would reinforce Lithuania's energy independence and would facilitate better resistance to a range of influences, which is a huge priceless value cherished by Lithuania's Government. EU has already made a decision to turn the European energy sector into a single network without any

areas bereft of energy security, as Lithuania is now. Admittedly, some interconnections (LitPol Link and NordBalt), which are a means to eliminate such areas, may not pay off in the short term and must therefore be supported by EU funds.

The prices of energy resources used to be low in Lithuania. They were extremely low during the entire Soviet period. Then the gas prices were also very low up until 2005: just $80 per thousand cubic metres, almost five times less than now. Experts believe the situation contributed to the attitude that from economic point of view, rather than political, nothing really needed to be done.

Lithuania, now paying about $400 per thousand cubic metres, struggles to negotiate with "Gazprom" at least the same gas prices as those paid by its neighbours Estonia and Latvia. Estonia pays $309 per thousand cubic metres, but it has an interconnection with Finland; Latvia pays $310, but it has gas storage facilities owned by Russia. But Lithuania is penalised for political reasons, because it embarked on implementing the EU gas directive on separation of transmission system operators, rather than for the failure to fulfil its obligations and buy the entire negotiated amount of gas. Estonia and Latvia managed to secure an exemption, but the past Seimas, Lithuania's parliament, assumed obligation to fulfil the directive.

Lithuanian experts believe that lower energy bills will help improve Lithuania's energy independence and security. In autumn 2012, a new unit of Lithuanian Power Plant will start working in Elektrėnai: rather as an attempt to ensure country's energy security and reliable supply than to achieve any economic goals. Its electricity cost is forecasted to exceed that of imported power. The new unit will replace older less efficient units and, in winter, will be more efficient than urban combined heat and power plants.

The time span for full transition from traditional buildings to construction of energy-efficient buildings is generally rather long. Painless reorganisation of the entire construction industry to adopt the newest technologies takes, for instance, about 12 to 20 years. The shift of mindsets and attitudes of participants in this process is equally important. Attempts to persuade construction firms proved to be particularly difficult, because construction of passive houses is both more costly and more complex, while civil engineers need excellent training.

The number of passive houses under construction varies constantly. During crisis people feel not too secure financially and revert to saving, which, in turn, led to plummeting demand for new passive houses. Demand fluctuations also much depend on state funding.

Public support to development of passive houses often is determined by the price. In countries where the price of one kilowatt-hour of electricity is relatively high, the interest in passive houses is very high. But just as oil prices start falling, the doubts return. German consumers already get monthly bills with

about 3% attributed to energy from renewable sources. Germans pay for such energy €10 billion per year. But since Germany has access to tons of cheap gas from Russia, public reaction is not at all times favourable. Each new law in effect transforms into a new item in the bill, thus people need motivation, and the government needs to find the best pace for transition to renewable sources. Otherwise voters may shift to other options at the next elections.

The production cost of energy from renewable sources is high; the state supports such production by subsidies and tries to improve its efficiency. As of 1 January 2012, producers of renewable energy, for instance, must take part in auctions of such renewable energy sources.

2.4. Self-expression values, environmentalism, global warming and the passive houses

The World Values Surveys were designed to measure all major areas of human concern, from religion to politics to economics and social life. It turns out that two dimensions of values dominate the picture: (1) Traditional vs. Secular-rational and (2) Survival vs. Self-expression. These two dimensions explain more than 70 percent of the cross-cultural variance on scores of more specific values. Survival values involve a priority of security over liberty, distrust in outsiders and a weak sense of happiness. Self-expression values imply the opposite on all these accounts (Inglehart, Welzel 2005).

2.4.1. Self-expression values and environmentalism

Scholars and practitioners from various countries (Inglehart 1995; Martinez-Alier 1995; Martinez-Alier 2000; Davey 2009; Guha, Martínez-Alier 1997) analyzed the interrelationship between environmentalism and post-materialist values, such as self-expression and quality of life. The connectedness of several of these is further described in brief.

There are two distinct environmental movements – the materialist and the post-materialist movements. Post-materialist environmental movements focus on "quality of life" values and conservation of wilderness and natural areas. Materialist environmental movements, known as "the environmentalism of the poor", are focused on the defense of environmental resources, which are needed for survival and livelihood or are a reaction against the increased impact of pollution and environmental degradation that create health risks. Post-materialist environmental movements are more often situated in industrialized, developed countries, and the materialist environmental movements are mainly located in

the third world (Guha, Martínez-Alier 1997). One such example is a campaign in the US that began in the 1980s against local pollution and toxic waste problems. The campaign highlighted the disproportionate number of toxic waste areas located in regions inhabited by poor people who happened to be "Afro, Hispanic or Native American". The issue highlighted the unfair burden placed on the poorest and the disenfranchised members of society (Martinez-Alier 2000).

In many respects, South Africans still regard the environment as a "luxury good" to be conserved when, and only when, other social and economic needs have been met. As a result many of the country's poorest people, who depend on direct water abstraction, wild harvesting of fuel and food and fodder, subsistence agriculture and soil fertility, are trapped in a cycle of ecological degradation and poverty precipitated by the very development process that was intended to assist them (Martinez-Alier 1995). Environmentalism of the poor was often overlooked, because it was seen to be more motivated by social issues and survival than concerned with the environment (Davey 2009). In addition Inglehart (Inglehart 1995; Inglehart 1997) suggests strong positive correlations between wealth and concern with environmentalism.

Franzen and Meyer (2010) review some theoretical approaches that try to explain individual as well as cross-national differences in environmental attitudes. Particularly Franzen and Meyer (2010) discuss Inglehart's theory of post-materialism, Dunlap and Mertig's globalization explanation and the prosperity hypothesis. Secondly Franzen and Meyer (2010) test these hypotheses by applying multilevel analysis to the International Social Survey Programme (ISSP) data from the years 1993 and 2000. The results support, above all, the prosperity hypothesis. Individuals with higher relative income within countries display higher levels of environmental concern than their compatriots and, additionally, more concern is reported in wealthier countries than in poorer nations. The results indicate that environmental concern is also closely associated with post-materialistic attitudes and various socio-demographic variables (Franzen, Meyer 2010).

2.4.2. Passive houses, global warming, zero carbon emissions and self-expression values

Three critical issues that our world faces today are energy conservation, global warming and the need for more quality housing. The solutions to these issues, however, do not always seem to fall neatly in line: How can we decrease carbon dioxide emissions and reduce energy use in existing homes whilst simultaneously dealing with increased energy demand and emissions due to the growing overall number of homes? Housing must boast dramatic reductions in

energy consumption and zero carbon emission for a desirable environment to form, which will live up to passive houses standards.

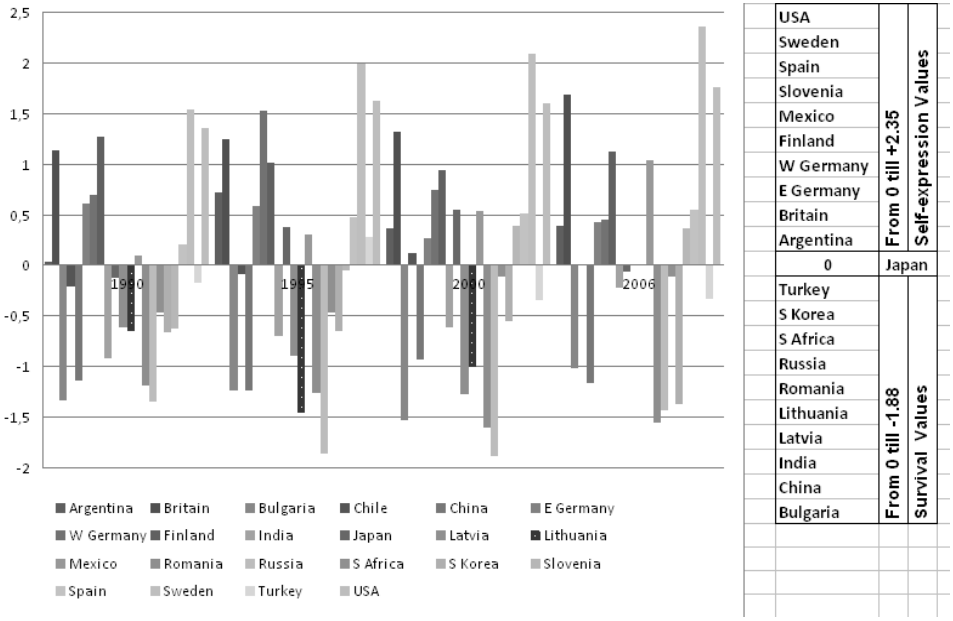


Fig. 2.2. The shift from survival values (bottom part) to self-expression values (upper part) indicate slightly better conditions for developing the passive houses in Lithuania (-0.64 in 1990, -1.45 in 1995, -1 in 2000 and 0 in 2006; in red colour with dots) (World Values Surveys). Self-expression values are scaled from 0 till 2.5 scale, with a 2.5 score on the scale indicate the achieving of the highest Self-expression values. Survival values are scored on a 0 till –2 scale, with a –2 score on the scale indicate the achieving of the lowest Survival values

The circumstances under which societies adapt their cultural values to cold, temperate or hot climates must include the availability of money to cope with climate. In a country-level study, collective income, household income and economic growth were conceptualized as moderators of the climate-culture link, because money is primarily used to satisfy homeostatic needs for thermal comfort, nutrition and health. The results demonstrate that members of societies in more demanding climates endorse survival values at the expense of self-expression values to the extent that they are poorer (n = 74 nations). Houses hold incomes in these lower-income societies are lower (n = 66 nations), and such societies face more economic recessions (n = 38 nations). In addition to theoretical implications, the findings have practical implications for the cultural consequences of global warming and the effectiveness of financing for human development (Van de Vliert 2008). A 104-nation study first demonstrates that

cultural self-expression, individualism and democracy languish in poor countries with colder-than-temperate winters, but flourish in rich countries with such winters (Van de Vliert 2011).

Currently Lithuania conveys survival values according to the criterion of "self-expression values" as per World Values Surveys (see Fig. 2.2). It can be claimed, on the basis of the aforementioned studies, that such a situation does not foster the development of the passive houses in Lithuania. The existing state of affairs in Lithuania substantiates this claim. Only two passive houses of single-family residency have been constructed at this time in Lithuania. However, now the situation has shifted slightly towards self-expression values.

The shift from survival values (Figure 2.2, bottom part) to self-expression values (upper part) is very slow in Lithuania. We shall make an EU-level relative analysis of this process by looking at the residential construction and building maintenance costs in four countries (Lithuania, Denmark, Sweden and Finland) between 1995 and 2008. We shall focus on the following indicators:

- Construction cost index, residential buildings (2005 = 100%).
- Comparative price level indices for housing costs (gross rent, fuel and power) (EU-27 = 100%).
- Share of households that perceive housing costs without financial burden (%) (2005/2008).
- Low income households by tenure and households receiving housing allowances (2008).
- Housing consumption as share of total (culture, food, clothing, etc). household consumption (%) (2000/2007).

Table 2.2 presents the EU-level relative analysis of residential construction costs in four countries (Lithuania, Denmark, Sweden and Finland) between 1995 and 2008. Between 1995 and 2008 the Construction Cost Index (residential buildings, 2005 = 100%) in the countries considered here increased from 37.8% (in Finland) to 124.2% (in Lithuania). In the same period the changes of GDP per capita in Purchasing Power Standards (EU-27 = 100%) varied greatly in these countries: increased in Lithuania (73.9%) and Finland (8.4%), but dropped in Denmark (8.9%) and Sweden (4.3%). Since all countries started from very unequal economic situations in 1995, it seems logical. In 1995 GDP per capita at current prices was €1,400 in Lithuania, €19,600 in Finland, €26,600 in Denmark, and €22,000 in Sweden, but the relative growth rate of this indicator was considerably higher in Lithuania and by 2008 the GDP per capita at current prices there had reached €9,600, while it amounted €42,400 in Denmark, €34,700 in Finland, and €35,400 in Sweden. It seems therefore plausible to say that over the 13-year period the increase of the relative construction cost at EU level (in light of the changes of the Construction Cost Index and GDP per capita in Purchasing Power Standards) in Lithuania (124.2% – 73.9% = 50.3%) and

Finland (37.8% – 8.4% = 29.4%) was lower than in Denmark (48.3% – (–8.9)% = 57.2%) and Sweden (63.6% – (–4.3)% = 67.9%). It means that Lithuania, in terms of the residential construction costs and compared to Scandinavian countries, experienced a slow shift from survival values to self-expression values (relative drop of construction costs leaves more resources for self-expression). Such events facilitate development of passive houses in Lithuania.

Table 2.2. EU-level relative analysis of residential construction costs in four countries (Lithuania, Denmark, Sweden and Finland) between 1995 and 2008

Indices	Lithuania	Denmark	Sweden	Finland
1. Construction Cost Index, residential buildings (2005 = 100%): - years 1995 and 2008 - increase, %, between 1995 and 2008	62.8/140.8 +124.2%	77.5/114.9 +48.3%	71.4/116.8 +63.6%	82.9/114.2 +37.8%
2. GDP per capita in Purchasing Power Standards (EU-27=100%): - years 1995 and 2008 - increase, %, between 1995 and 2008	35.6/61.9 +73.9%	131.8/120.1 -8.9%	125.4/120 -4.3%	107.7/116.8 +8.4%
Between 1995 and 2008 a relative EU-level increase of the Construction Cost Index was recorded (Construction Cost Index – GDP per capita in Purchasing Power Standards)	50.3%	57.2%	67.9%	29.4%

Source: Eurostat

Table 2.3 shows the EU-level relative analysis of price level indices for housing costs (gross rent, fuel and power; EU-27 = 100%) in four countries (Lithuania, Denmark, Sweden and Finland) between 2000 and 2008. Table 2.3 shows that the highest increase of Comparative Price Level indices for housing costs over the analysed 9-year period (between 2000 and 2008) was in Lithuania (46%), followed by Denmark (12%) and Finland (2.5%), while Sweden recorded a drop of 17.8%. Meanwhile, Lithuania's GDP per capita in Purchasing Power Standards increased over the same period by as many as 57.5%, while it dropped in Denmark (8.7%), Sweden (5.3%) and Finland (0.3%). It seems therefore

plausible to state that over the 9-year period the EU-level Comparative Price Level indices for housing costs (in view of the changes of the GDP per Capita in Purchasing Power Standards) relatively dropped in Lithuania (46% – 57.5% = –11.5%) and Sweden (–17.8% – (–5.3)% = –12.5%), but relatively increased in Denmark (12% – (–8.7)% = 20.7%) and Finland (2.5% – (–0.3)% = 2.8%). It means that over the 9-year period residential buildings maintenance costs dropped in Lithuania (compared to Scandinavian and EU countries), leaving more resources for self-expression values; which from a certain viewpoint encourages passive houses development in Lithuania.

Table 2.3. EU-level relative analysis of price level indices for housing costs (gross rent, fuel and power; EU-27 = 100%) in four countries (Lithuania, Denmark, Sweden and Finland) between 2000 and 2008

Indices	Lithuania	Denmark	Sweden	Finland
Comparative price level indices for housing costs (gross rent, fuel and power) (EU-27 = 100%): - years 2000 and 2008 - increase, %, between 2000 and 2008	31.1/45.3 +46%	140.0/157.4 +12%	136.2/112.0 -17.8%	130.1/133.3 +2.5%
GDP per capita in Purchasing Power Standards (EU-27=100%) - years 2000 and 2008 - increase, %, between 2000 and 2008	39.3/61.9 +57.5%	131.6/120.1 -8.7%	126.7/120 -5.3%	117.1/116.8 -0.3%
Between 2000 and 2008 a relative EU-level change of the housing costs was recorded (Comparative price level indices for housing costs – GDP per capita in Purchasing Power Standards)	Relatively decrease, 11.5%	Relatively increase, 20.7%	Relatively decrease, 12.5%	Relatively increase, 2.8%

Source: Eurostat

Analyses of other similar indicators lead to equivalent conclusions (see Table 2.4).

Table 2.4. Other similar indicators

Indices	Lithuania	Denmark	Sweden	Finland
Share of households that perceive housing costs without financial burden (%) (years 2005 and 2008)	14.9/16.5	73.2/69.6	50.4/52.7	24.1/23.1
Low income households by tenure and households receiving housing allowances (2008)	19	12	11	13
Housing consumption as share of total (culture, food, clothing, etc) household consumption (%) (years 2000 and 2007).	17.0/13.6	26.6	27.8	24.7/24.7

Source: Eurostat

Household consumption habits vary substantially among the EU Member States. Factors such as culture, income, weather, household composition, economic structure and degree of urbanisation can all influence habits in each country (Eurostat).

2.5. Passive houses weaknesses in Lithuania

The following passive houses weaknesses in Lithuania were established during the time of the project, "Promotion of the Passive houses Concept to the North European Building Market" (NorthPass):

- Lithuania's Law on Construction and its Technical Construction Regulations are not tailored for passive houses. Passive houses were designed on the basis of the Finish, Swedish and German experiences.
- Administrative and public procurement procedures are too slow. In particular the process of obtaining decisions, permits, certificates and such from public authorities is too time-consuming causing it to be too slow for the commencement of large-scale public projects.
- The Energy Performance of Passive houses Directive is not yet fully concerned with relevant, already existing standards and norms for passive houses in Lithuania.
- There is no certification of low energy design and construction experts yet. Certification of low energy products is insufficient. There is minimal information on assessed low energy houses found to have a reasonable energy and indoor climate performance.

- There is a shortage of feedback from previously known explicit and tacit information and from new low energy houses. There is a belief that building low energy houses is more expensive than the usual construction. Thus on-site problems can't always be solved.
- A tenants´ association does not always have the necessary competence. Real estate management organizations are often uninvolved. Too many prejudices from the energy saving measures from the eighties exist. Workmanship for thermal insulation has too low a status. Workers can be prejudiced regarding new methods. There are too few contractors, developers and property managers who are indoor climate and energy experts.
- The passive houses and low energy design theory is not sufficiently introduced in Lithuanian bachelor and master degree study programs.
- Users lack knowledge to be able to assess the pluses of a low energy passive houses (comfort, low noise, economic efficiency). As a result, the low energy, passive houses remains unknown and demand fails to grow.
- The media fail to deliver sufficient information to stimulate interest in passive homes and to motivate professionals and decision makers.
- Scientists lack knowledge about the needs of users and contractors. Therefore it becomes complicated for architects, designers and contractors to stay up-to-date about new energy saving products, materials and systems.
- Education faces a fragmentation problem. Each player (owner, user, developer, architect, designer, consultant, contractor, manufacturer, user, real estate and facilities manager) generally has highly narrow knowledge, in his/her own field alone.
- There are too few financials incentives (calls for projects, subsidies, energy labels and such) for developing lifelong learning about passive houses (web portal, seminars and workshops, technical publications presenting the codes, case studies).
- Since the market for passive houses is limited, prices for them continue increasing. Large scale production is currently inapplicable; therefore nonproductive efforts of all types are impossible to reduce, including labor and construction cost s, and the rate of production cannot be increased to reduce the time for construction.
- Different stakeholders design a passive house integrating its full lifecycle insufficiently.
- The price of equipment (e.g., recuperators) and structural solutions (e.g., windows) is quite high considering the salaries and the amount of energy saved. Savings, in relation to investments, are low.

- There are no land tax reductions, and land is not sold at a lower price for the construction of passive houses. The plot ratio is not higher in case of passive construction.
- Fees are not designed to reward designers and architects of passive houses that have low maintenance and low lifecycle costs. There are no available subsidies for research development on the energy consumption and on the most rational energy sources to be used for a passive house under consideration.
- The level of the VAT level is too high on an entire list of equipment types that can increase energy efficiency in the domestic sector (efficient boilers, insulation and energy meters and such). There are no tax credit schemes in place to provide real estate owners who purchase energy saving or energy renewing equipment with an income tax refund. Furthermore there are no specific loans in place that would grant interest rate reductions in whole or in part. Banks are not accustomed to funding energy savings when issuing loans for a specific passive house.
- The more energy costs increase, the greater the demand for passive houses will be.

Stakeholders only agree on one key aspect. The cases of other countries teach a lesson only the state can put in motion the construction of energy efficient and environment-friendly houses. The range of incentives is huge, from tax benefits to easy credit terms or even a substantial discount for fuels for a certain period (Pasyvus būstas, 2008).

2.6. Conclusions from Chapter 2

1. An original model of a complex analysis of a passive houses knowledge enabling the user to analyze a passive houses life cycle and its stages, the parties involved in the project as well as its micro, mezzo and macro environments as an integral whole is developed.
2. An original passive houses knowledge model is developed on the basis of complex systems theory and the models of the multiple criteria analysis. Model includes the six stages: (1) comparative description of the passive houses knowledge; (2) comparison of the passive houses knowledge and trends; (3) multiple criteria analysis of the components of passive houses and selection of most efficient components; (4) development of general recommendations; (5) submission of certain recommendations to stakeholders; (6) transformational learning and changing of mental and practical

behavior. The model of passive houses knowledge was verified in operational conditions and supports its viability.

3. A passive house life cycle as well as the parties involved in the project and the environment having a certain impact on it are described from various perspectives in numerous publications by the author in quantitative (a system and subsystems of criteria, units of measure, values and significances) and conceptual (text, formula, graphical (i.e. schemes, graphs, diagrams and video tapes) forms. The suggested systems and subsystems of criteria relating to a passive house life cycle and based on economic, technical, technological, qualitative (i.e. comfortability, architectural, aesthetic, and the like), legislative, social and other factors are described in a number of publications.

3

Multiple criteria decision support system for passive houses knowledge

In this chapter multivariant design and multiple criteria analysis of the components of a passive houses are presented. It reviews the preparation procedure for input data, describes the suggested model for multivariant design and multiple criteria analysis of the components of passive houses, and presents the process and methodology of analysis. Multiple criteria decision support system for passive houses knowledge designed on the basis of the model proposed by the author. The chapter deals in detail with the system's elements and explains the principle of its operation.

Two articles dealing with the topics discussed in this chapter were published (Kaklauskas *et al.* 2011; Kaklauskas *et al.* 2012).

3.1. Gathering of initial data for multiple criteria analysis

The determination of the utility degree and value of the project under investigation and establishment of the priority order for its implementation does

not present much difficulty if the criteria numerical values and significances have been obtained and the multiple criteria decision making methods are used.

All criteria are calculated for the whole project. The process of determining the system of criteria, their initial significances and qualitative criteria numerical values of the project under investigation is based on the use of various expert methods (Kaklauskas *et al* 2006b). The determination of quantitative criteria numerical values is based on the use of various statistical methods, analysed projects, recommendations, price-lists, reference books, building codes, specifications and other documents. For example, values of qualitative criteria may be obtained as follows by applying the expert methods:

- the best suitable alternative is chosen according to a specific criterion;
- the considered criterion of the selected best alternative is set equal to the magnitude of one point (x_{ger}=1);
- the ratio (p_i) amongst all the rest alternatives of the corresponding criterion magnitudes and the best criterion magnitude is determined;
- the criteria are given relative values (x_i= p_i);
- relative values of all criteria are recalculated so that their sum makes one (Zavadskas, Kaklauskas 1994).

The results (see Table 3.1) of the comparative analysis of the projects are presented as a grouped decision making matrix where columns contain *n* alternative projects being considered, while all quantitative and conceptual information pertaining to them is found in lines (Zavadskas *et al.* 1996d).

Quantitative and conceptual description of the research object provides the information about various aspects of a PHK (i.e. economical, technical, technological, infrastructural, qualitative, etc). Quantitative information is based on the criteria systems and subsystems, units of measure, values and initial significances as well as the data on the alternative projects development.

Conceptual description of a PHK presents textual, graphical (schemes, graphs, diagrams, drawings), visual (videotapes) information about the projects and the criteria used for their definition, as well as giving the reason for the choice of this particular system of criteria, their values and significances. This part also includes information about the possible ways of multivariant design. Conceptual information is needed to make more complete and accurate evaluation of the alternatives considered. It also helps to get more useful information as well as developing a system and subsystems of criteria and defining their values and significances.

The grouping of the information in the matrix should be performed so as to facilitate the calculation process and to express their physical meaning. In our case the criteria system are formed from the criteria describing the life cycle of a building which can be expressed in a quantitative form (quantitative criteria) and the criteria describing the life cycle of a building which cannot be expressed in a

quantitative form (qualitative criteria) (Kaklauskas *et al.* 2001; Kaklauskas, Zavadskas 2002a; Kaklauskas *et al.* 2002b; Kaklauskas *et al.* 2007a).

In order to perform a complete study of the research of passive houses knowledge, a complex evaluation of its economic, technical, qualitative, technological, social, legislative, infrastructural and other aspects is needed. The diversity of aspects being assessed should follow the diversity of ways of presenting data needed for decision making. Therefore, the necessary data may be presented in numerical, textual, graphical (schemes, graphs, charts), formula, videotape and other forms.

Table 3.1. Grouped decision making matrix of PHK multiple criteria analysis

Quantitative information pertinent to PHK									
Criteria describing the passive houses	*	Significance	Measuring	Compared projects 1	2	...	j	...	n
Quantitative criteria	z_1	q_1	units	x_{11}	x_{12}	…	x_{1j}	…	x_{1n}
	z_2	q_2	m_2	x_{21}	x_{22}	…	x_{2j}	…	x_{2n}
	...	...	...	...	...	…	...	…	...
	z_i	q_i	m_i	x_{i1}	x_{i2}	…	x_{ij}	…	x_{in}
	...	...	...	...	...	…	...	…	...
	z_t	q_t	m_t	x_{t1}	x_{t2}	…	x_{tj}	…	x_{tn}
Qualitative criteria	z_{t+1}	q_{t+1}	m_{t+1}	$x_{t+1\,1}$	$x_{t+1\,2}$	…	$x_{t+1\,j}$	…	$x_{t+1\,n}$
	z_{t+2}	q_{t+2}	m_{t+2}	$x_{t+2\,1}$	$x_{t+2\,2}$	…	$x_{t+2\,j}$	…	$x_{t+2\,n}$
	...	...	...	...	...	…	...	…	...
	z_i	q_i	m_i	x_{i1}	x_{i2}	…	x_{ij}	…	x_{in}
	...	...	...	...	...	…	...	…	...
	z_m	q_m	m_m	x_{m1}	x_{m2}	…	x_{mj}	…	x_{mn}
Conceptual information pertinent to projects (i.e. text, drawings, graphics, video tapes)									
				K_1	K_2	…	K_j	…	K_n

∗ - The sign z_i (+ (–)) indicates that a greater (less) criterion value corresponds to a higher significance for a client

3.2. Adapted method of multivariant design and multiple criteria analysis of passive houses and its components

According to the Method of Multiple Criteria Complex Proportional Evaluation (COPRAS) developed by Zavadskas and Kaklauskas (1996a), the determination of significance, priority and utility degree of alternatives is carried out in the first six stages. These stages assume direct and proportional dependence of significance and the utility degree of investigated versions on a system of

criteria that adequately describes the alternatives, and values and weights of the criteria. A decision maker by using the best practices of similar situations and experts' methods determines the system of criteria and calculates the values and initial weights of qualitative criteria. Multivariant design and multiple criteria analysis of the whole life cycle of a passive house are carried out in next six stages.

3.2.1. Determination of the significance, utility degree and priority of all the passive house and its components

While carrying out passive house and its components it is rational to analyze all its possible combinations. In order to create possible combinations, the efficiency of separate elements (windows, walls, thermal units, roof, etc) of passive houses and its components should be analyzed. The efficiency of these separate elements of passive house and its components is estimated during the first five stages. Stage six repeats the first five stages till the significance, utility degree and priority of all the passive house and its components were estimated.

Stage 1. The weighted normalized decision making matrix D is formed (Table 3.2). The purpose of this stage is to receive dimensionless weighted values from the comparative indexes. When the dimensionless values of the indexes are known, all criteria, originally having different dimensions, can be compared. The following formula is used for this purpose:

$$d_{ij} = \frac{x_{ij} \cdot q_i}{\sum_{j=1}^{n} x_{ij}}, \quad i = \overline{1,m}; \quad j = \overline{1,n}, \tag{3.1}$$

where x_{ij} – the value of the i-th criterion in the j-th alternative of a solution; m – the number of criteria; n – the number of the alternatives compared; q_i – significance of i-th criterion.

The sum of dimensionless weighted index values d_{ij} of each criterion x_i is always equal to the significance q_i of this criterion:

$$q_i = \sum_{j=1}^{n} d_{ij}, \quad i = \overline{1,m}; \quad j = \overline{1,n}. \tag{3.2}$$

In other words, the value of significance q_i of the investigated criterion is proportionally distributed among all alternative versions a_j according to their values x_{ij}.

Stage 2. The sums of weighted normalized indexes describing the j-th version are calculated. The versions are described by minimizing indexes S_{-j} and

maximizing indexes S_{+j}. The lower value of minimizing indexes is better (passive house elements price, etc). The greater value of maximizing indexes is better (the level of security, reliability, etc). The sums are calculated according to the formula:

$$S_{+j} = \sum_{i=1}^{m} d_{+ij}; \tag{3.3}$$

$$S_{-j} = \sum_{i=1}^{m} d_{-ij}, \quad i = \overline{1,m}; \quad j = \overline{1,n}. \tag{3.4}$$

In this case, the values S_{+j} (the greater is this value (project ”pluses”), the more satisfied are the interested parties) and S_{-j} (the lower is this value (project ”minuses”), the better is goal attainment by the interested parties) express the degree of goals attained by the interested parties in each alternative project. In any case the sums of ”pluses” S_{+j} and ”minuses” S_{-j} of all alternative projects are always respectively equal to all sums of significances of maximizing and minimizing criteria:

$$S_{+} = \sum_{j=1}^{n} S_{+j} = \sum_{i=1}^{m} \sum_{j=1}^{n} d_{+ij}, \tag{3.5}$$

$$S_{-} = \sum_{j=1}^{n} S_{-j} = \sum_{i=1}^{m} \sum_{j=1}^{n} d_{-ij}, \quad i = \overline{1,m}; \quad j = \overline{1,n}. \tag{3.6}$$

In this way, the calculations made may be additionally checked.

Stage 3. The significance (efficiency) of comparative versions is determined on the basis of describing positive projects (”pluses”) and negative projects (”minuses”) characteristics. Relative significance Q_j of each project a_j is found according to the formula:

$$Q_j = S_{+j} + \frac{S_{-\min} \cdot \sum_{j=1}^{n} S_{-j}}{S_{-j} \cdot \sum_{j=1}^{n} \frac{S_{-\min}}{S_{-j}}}, \quad j = \overline{1,n}. \tag{3.7}$$

Stage 4. Priority determination of projects. The greater is the Q_j the higher is the efficiency (priority) of the project.

The analysis of the method presented makes it possible to state that it may be easily applied to evaluating the projects and selecting most efficient of them, being fully aware of a physical meaning of the process. Moreover, it allowed to formulate a reduced criterion Q_j which is directly proportional to the relative effect of the compared criteria values x_{ij} and significances q_i on the end result.

Table 3.2. Passive houses knowledge multiple criteria analysis results

Quantitative information describing the alternatives									
Criteria describing the passive houses	*	Signi-fican-	Measu-ring	Compared projects 1	2	...	j	...	n
X_1	z_1	ce	units	d_{11}	d_{12}	…	d_{1j}	…	d_{1n}
X_2	z_2	q_2	m_2	d_{21}	d_{22}	…	d_{2j}	…	d_{2n}
X_3	z_3	q_3	m_3	d_{31}	d_{32}	…	d_{3j}	…	d_{3n}
…	...	...	...	...	...	…	...	…	...
$_i$	z_i	q_i	m_i	d_{i1}	d_{i2}	…	d_{ij}	…	d_{in}
…	...	...	...	...	...	…	...	…	...
X_m	z_m	q_m	m_m	d_{m1}	d_{m2}	…	d_{mj}	…	d_{mn}
The sums of weighted normalized maximizing (projects "pluses") indices of the project				S_{+1}	S_{+2}	…	S_{+j}	…	S_{+n}
The sums of weighted normalized minimizing (projects "minuses") indices of the project				S_{-1}	S_{-2}	…	S_{-j}	…	S_{-n}
Significance of the project				Q_1	Q_2	…	Q_j	…	Q_n
Priority of the project				P_1	P_2	…	P_j	…	P_n
Utility degree of the project (%)				N_1	N_2	…	N_j	…	N_n

** - The sign z_i (+ (–)) indicates that a greater (less) criterion value corresponds to a greater significance for a client*

Significance Q_j indicates satisfaction degree of demands and goals pursued by the interested parties – the greater is the Q_j the higher is the efficiency. In this case, the significance Q_{max} will always be the highest. The significances of all remaining criteria are lower as compared with the most rational one. This means that total demands and goals of interested parties will be satisfied to a smaller extent than it would be in case of the best choise (Zavadskas *et al.* 1995).

The degree of project utility is directly associated with quantitative and conceptual information related to it. If one project is characterized by the best comfortability, aesthetics, price indices, while the other shows better maintenance and facilities management characteristics, both having obtained the same significance values as a result of multiple criteria evaluation, this means that their utility degree is also the same. With the increase (decrease) of the significance of a project analyzed, its degree of utility also increases (decreases). The degree of property utility is determined by comparing the project analysed with the most efficient project (Zavadskas, Kaklauskas 1996c).

In this case, all the utility degree values related to the project analyzed will be ranged from 0% to 100%. This will facilitate visual assessment of intelligent passive house and its components efficiency

Stage 5. The formula used for the calculation of intelligent passive houses knowledge a_j utility degree N_j is given below:

$$Nj = \left(\frac{Q_j}{Q_{\max}} \right) \cdot 100\ \%. \tag{3.8}$$

The degree of utility *Nj* of project aj indicates the level of satisfying the needs of the parties interested in the project. The more goals are achieved and the more important they are, the higher is the degree of the project utility. Since clients are mostly interested in how much more efficient particular project are than the others (which ones can better satisfy their needs), then it is more advisable to use the concept of project utility rather than significance when choosing the most efficient solution (Zavadskas, Kaklauskas 1996c).

Thus, having determined in such a way the ratio of degree of utility and market value of property, one can see what complex effect can be obtained by investing money into anyone of the property. There is a complete clarity where it pays better to invest the money and what is the efficiency degree of the investment.

Stage 6. Determination of the significance, utility degree and priority of all passive houses knowledge. Further on, one repeats the first five stages till the significance, utility degree and priority of of all the passive house and its components were estimated (see Table 3.3).

Table 3.3. Most efficient solution alternatives set according their priorities

Solutions considered	Priority of the best alternative solutions						
	1	2	3	...	*j*	...	*p*
1.Windows variants, Q_1	a_{11}	a_{12}	a_{13}	...	a_{1j}	...	a_{1p}
2. Doors variants, Q_2	a_{21}	a_{22}	a_{23}	...	a_{2j}	...	a_{2p}
...	...	...	...	...	...	...	...
i. Roofs variants, Q_i	a_{i1}	a_{i2}	a_{i3}	…	a_{ij}	…	a_{ip}
...	...	...	...	...	...	...	...
c. Walls variants. Q_c	a_{c1}	a_{c2}	a_{c3}	...	a_{cj}	...	a_{cp}

3.2.2. Multivariant design and multiple criteria analysis of the whole passive houses knowledge

Much data had to be processed and evaluated in carrying out the multivariant design and multiple criteria analysis of a passive houses knowledge. Numbers of feasible alternatives can be as large as 100.000. Each of the alternatives may be

described from various perspectives, e.g. by conceptual and quantitative information. The problem arises as how to perform design and multiple criteria analysis of the alternatives, based on this enormous amount of information. To solve this problem, multivariant design and multiple criteria analysis of the whole passive houses knowledge are carried out in stages 7–12 (Fig. 3.1). These stages are briefly described below.

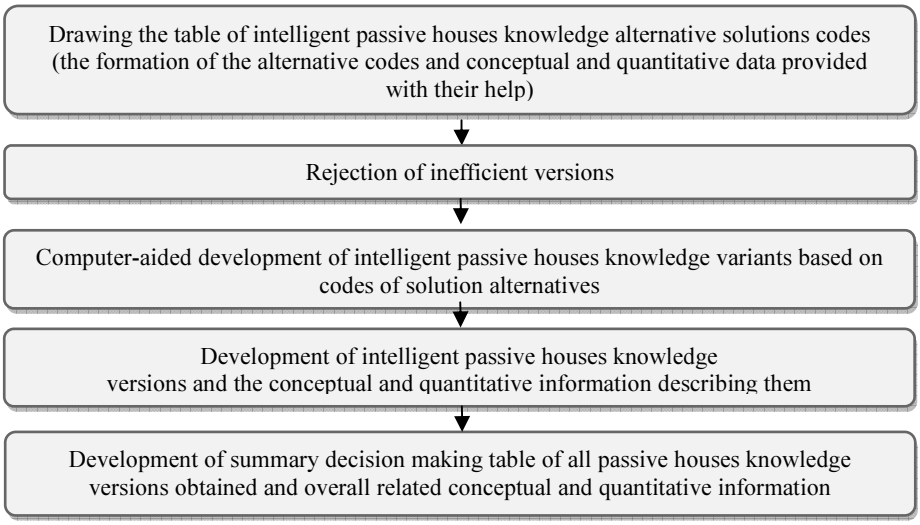


Fig. 3.1. Main stages of multiple criteria multivariant design of a passive houses knowledge variants

Stage 7. Passive houses most efficient solution alternatives set according their priorities. For example, if in determining possible PHK alternative versions 10 alternatives are considered for any of 10 solutions, then, according to equation 3.7 maximum ten billion such variants will be obtained. It is evident that in this and similar cases it is hardly possible and reasonable to analyze all the
versions from various perspectives. Therefore, it is advisable to reduce their number as follows. If a project of c solutions having n_i alternatives allows k combinations (equation 3.7) then, by using multiple criteria analysis methods, p most efficient versions should be chosen from every solution for further consideration (see Table 3.3). In this way, inefficient variants are being removed. The best solutions alternatives obtained are then grouped according to priority considerations. In Table 3.3 a_{i1} is a code of the best variant of i solution, while a_{ip} is a code of its worst version (Zavadskas *et al.* 1998).

Stage 8. In order to reduce the amount of information being used in computer-aided multivariant design the codes of the alternative solutions are

used. In this case, any i solution of j alternative is given a_{ij} code providing thorough quantitative (system of criteria, units of measure, significances, values, as well as a minimizing or maximizing criterion) and conceptual (text, drawings, graphics, video tapes) information about the alternative being considered (see Table 3.4). Thus, the use of codes of the alternative solutions in computer-aided multivariant design reduces the volume of information to be processed providing better insight into a physical meaning of computations (Zavadskas *et al.* 1998).

Table 3.4. Codes of intelligent passive house and its component alternative solutions with conceptual and quantitative information

Solutions considered	The codes of the alternative solutions considered						
	1	2	3	...	j	...	n_i
1.Windows variants, Q_1	a_{11}	a_{12}	a_{13}	...	a_{1j}	...	$a_{1\,n1}$
2. Doors variants, Q_2	a_{21}	a_{22}	a_{23}	...	a_{2j}	...	$a_{2\,n2}$
...	...	...	...	...	...	...	...
i. Roofs variants, Q_j	a_{i1}	a_{i2}	a_{i3}	...	$\boldsymbol{a_{ij}}$	...	$a_{i\,ni}$
...	...	...	...	...	...	...	...
c. Walls variants, Q_c	a_{c1}	a_{c2}	a_{c3}	...	a_{cj}	...	$a_{c\,nc}$

The information provided by code $\boldsymbol{a_j}$ of i solution j alternative

Conceptual information (text, drawings, graphics, videotapes)	Quantitative information						
	Cost, X_1	Aesthe-tics, X_2	Comfortabi-lity, X_3	…	X_j	…	Means of transport, X_n
K_{ij}	$x_{ij\,1}$	$x_{ij\,2}$	$x_{ij\,3}$	...	$x_{ij\,j}$	...	$x_{ij\,n}$
Units of measure	Lt	Points	Points	…	…	…	Points
Significance	$q_{i\,1}$	$q_{i\,2}$	$q_{i\,3}$	...	$q_{i\,j}$	...	$q_{i\,n}$
*	$z_{i\,1}$	$z_{i\,2}$	$z_{i\,3}$	...	$z_{i\,j}$	...	$z_{i\,n}$

** - Signs z_{ij} (+ (–)) mean, that corresponding higher (lower) value of the criterion better satisfies the client's needs*

Codes, with conceptual and quantitative information provided, are used for describing all available alternative project solutions. The total number of these codes makes the table of codes of PHK alternatives allowing to get the alternative versions in a more simple way (see Table 3.4). As can be seen from Table 3.4, it contains c solutions of a PHK (plots, buildings, contractors, maintenance process, etc) of the n_i alternative versions codes. Any i line of the code table represents the codes of A_i solution a_{ij} alternatives. If the information relating to the solutions in the code table of PHK alternatives is represented by codes, then the code contains quantitative and conceptual information (see Table 3.4). In this case, n_i alternatives of any i solution are being considered in

developing the alternative versions of a PHK. Thus, the maximum number of the projects obtained may be computed as follows:

$$k = \prod_{i=1}^{c} n_i, \tag{3.9}$$

where c is the number of solutions considered in determining a PHK; n_i – is the number of i solution alternatives to be used in developing a PHK.

Stage 9. Then, project variants are being developed based on the efficient p alternatives of c solutions chosen. At the beginning, this process should involve the codes of the alternative solution`s. The first PHK variant is obtained by analyzing the best solution variants according to the priority order (see Table 3.5).

Table 3.5. Development of passive house and its components alternatives based on codes of solution variants

Solutions considered	The formation of versions of passive house and its components											
	1	2	3	...	p	p+1	p+2	p+3	...	2p	...	K
1. Windows variants	a_{11}	a_{11}	a_{11}	...	a_{11}	a_{11}	a_{11}	a_{11}	...	a_{11}	...	a_{1p}
2. Doors variants	a_{21}	a_{21}	a_{21}	...	a_{21}	a_{21}	a_{21}	a_{21}	...	a_{21}	...	a_{2p}
...	...	...	...	...	...	...	...	...	...	...	...	...
i. Roofs variants	a_{i1}	a_{i1}	a_{i1}	...	a_{i1}	a_{i1}	a_{i1}	a_{i1}	...	a_{i1}	...	a_{ip}
...	...	...	...	...	...	...	...	...	...	...	...	...
c–1	$a_{c\text{-}1\ 1}$	$a_{c\text{-}1\ 1}$	$a_{c\text{-}1\ 1}$	...	$a_{c\text{-}1\ 1}$	$a_{c\text{-}1\ 2}$	$a_{c\text{-}1\ 2}$	$a_{c\text{-}1\ 2}$	...	$a_{c\text{-}1\ 2}$	...	$a_{c\text{-}1\ p}$
c. Walls variants	a_{c1}	a_{c2}	a_{c3}	...	a_{cp}	a_{c1}	a_{c2}	a_{c3}	...	a_{cp}	...	$a_{c\ p}$

The last variant is based on solution versions from the bottom of priority table, while intermediate variants are obtained with account of the versions found in the middle of this table. For example, the first building components version is based on a_{11} windows, a_{21} doors, a_{i1} rooof, a_{c1} walls, etc variants. The last building components version takes into account a_{1p} windows, a_{2p} doors, a_{ip} roof, a_{cp} walls, etc variants. In this case, combinations are obtained by using p alternatives from any c solutions. Therefore, the maximum number of the projects obtained may be determined from the following expression:

$$K = \prod_{i=1}^{c} p, \tag{3.10}$$

where c is the number of solutions used in determining a PHK; p is the number of the best variants of every solution used in developing a intelligent passive house and its components.

Stage 10. Development of passive house and its components alter-natives based on the conceptual and quantitative information. In Table 3.5 the development of passive house and its components altematives was based on codes of solution altematives. Table 3.7 presents conceptual and quantitative information about the altematives, instead of the codes. When aparticular passive house and its components is being considered, the values relating to various solutions but based on the same criterion are recalculated into a single reduced value.

Table 3.6. Development of intelligent passive house and its components variants and related conceptual and quantitative information

Passive houses	Information related to intelligent passive houses components							
	Conceptual	Quantitative						
		Cost, $\mathbf{X_1}$ (Lt)	Aesthetics, $\mathbf{X_2}$ (Points)	Comfortability, $\mathbf{X_3}$ (Points)	…	X_j	…	Means of transport, $\mathbf{X_n}$ (Points)
1	2	3	4	5	6	7	8	9
	Information related to of 1-st passive house and its components							
1. Windows, $\boldsymbol{a_{11}}$	$\boldsymbol{K_{11}}$	$x_{11\,1}$	$x_{12\,1}$	$x_{13\,1}$	…	$x_{1j\,1}$	…	$x_{1n\,1}$
2. Doors, $\boldsymbol{a_{21}}$	$\boldsymbol{K_{21}}$	$x_{21\,1}$	$x_{22\,1}$	$x_{23\,1}$	…	$x_{2j\,1}$	…	$x_{2n\,1}$
...		...	...	...	…	...	…	...
i. Roofs, $\boldsymbol{a_{i1}}$	$\boldsymbol{K_{i1}}$	$x_{i1\,1}$	$x_{i2\,1}$	$x_{i3\,1}$	…	$x_{ij\,1}$	…	$x_{in\,1}$
...		...	...	...	…	...	…	...
c. Walls, $\boldsymbol{A_{c1}}$	$\boldsymbol{K_{c1}}$	$x_{c1\,1}$	$x_{c2\,1}$	$x_{c3\,1}$	…	$x_{cj\,1}$	…	$x_{cn\,1}$
	Information related to of 2-nd passive house and its components							
1. Windows, $\boldsymbol{a_{11}}$	$\boldsymbol{K_{11}}$	$x_{/1\,1}$	$x_{12\,1}$	$x_{13\,1}$	…	$x_{1j\,1}$	…	$x_{1n\,1}$
2. Doors, $\boldsymbol{a_{21}}$	$\boldsymbol{K_{21}}$	$x_{21\,1}$	$x_{22\,1}$	$x_{23\,1}$	…	$x_{2j\,1}$	…	$x_{2n\,1}$
...		...	...	...	…	...	…	...
i. Roofs, $\boldsymbol{a_{i1}}$	$\boldsymbol{K_{i1}}$	$x_{i1\,1}$	$x_{i2\,1}$	$x_{i3\,1}$	…	$x_{ij\,1}$	…	$x_{in\,1}$
...		...	...	...	…	...	…	...
c. Walls, $\boldsymbol{A_{c1}}$	$\boldsymbol{K_{c2}}$	$x_{c1\,2}$	$x_{c2\,2}$	$x_{c3\,2}$	…	$x_{cj\,2}$	…	$x_{cn\,2}$
...	...	...	...	...	.	...	.	...
	Information related to of p-th passive house and its components							
1. Windows, $\boldsymbol{a_{11}}$	$\boldsymbol{K_{11}}$	$x_{11\,1}$	$x_{12\,1}$	$x_{13\,1}$	…	$x_{1j\,1}$	…	$x_{1n\,1}$

Table 3.6. continued

1	2	3	4	5	6	7	8	9
2. Doors, $\boldsymbol{a_{21}}$	$\boldsymbol{K_{21}}$	$x_{21\,1}$	$x_{22\,1}$	$x_{23\,1}$	…	$x_{2j\,1}$	…	$x_{2n\,1}$
...		...	...	...	…	...	…	...
i. Roofs, $\boldsymbol{a_{i1}}$	$\boldsymbol{K_{i1}}$	$x_{i1\,1}$	$x_{i2\,1}$	$x_{i3\,1}$	…	$x_{ij\,1}$	…	$x_{in\,1}$
...		...	...	...	…	...	…	...
c. Walls, $\boldsymbol{A_{c1}}$	$\boldsymbol{K_{cp}}$	$x_{c1\,p}$	$x_{c2\,p}$	$x_{c3\,p}$	…	$x_{cj\,p}$	…	$x_{cn\,p}$
	...	...	...	...	.	...	.	...
	Information related to ofthe last (*K*) passive house and its components							
. Windows, $\boldsymbol{a_{11}}$	$\boldsymbol{K_{1p}}$	$x_{11\,p}$	$x_{12\,p}$	$x_{13\,p}$	…	$x_{1j\,p}$	…	$x_{1n\,p}$
2. Doors, $\boldsymbol{a_{21}}$	$\boldsymbol{K_{2p}}$	$x_{21\,p}$	$x_{22\,p}$	$x_{23\,p}$	…	$x_{2j\,p}$	…	$x_{2n\,p}$
...		...	...	...	…	...	…	...
i. Roofs, $\boldsymbol{a_{i1}}$	$\boldsymbol{K_{ip}}$	$x_{i1\,p}$	$x_{i2\,p}$	$x_{i3\,p}$	…	$x_{ij\,p}$	…	$x_{in\,p}$
...		...	...	...	…	...	…	...
c. Walls, $\boldsymbol{A_{c1}}$	$\boldsymbol{K_{cp}}$	$x_{c1\,p}$	$x_{c2\,p}$	$x_{c3\,p}$	…	$x_{cj\,p}$	…	$x_{cn\,p}$

$\boldsymbol{a_{i1}}$ ($\boldsymbol{a_{ip}}$) – the best/worst variant of the solution i;
$\boldsymbol{a_{ik}}$ – the variant k of the solution i;
$\boldsymbol{K_{i1}}$ ($\boldsymbol{K_{ip}}$) – qualitative information about the best/worst variant of the solution i;
$\boldsymbol{K_{ik}}$ – qualitative information about the variant k of the solution i;
$\boldsymbol{x_{ij1}}$ ($\boldsymbol{x_{ijp}}$) – the value of the best/worst variant of the criterion j of the solution i;
$\boldsymbol{x_{ijk}}$ – the value of the criterion j of the solution i in the variant k.

Stage 11. Development of a summarized decision making table of passive house and its components versions obtained and the overall related conceptual and quantitative information. When reducing the same criterion e.g. cost and comforts values of various solutions, to a single one, it is necessary to appraise the weights of these solutions. For example, noise level inside and outside the building is not of equal importance to inhabitants. The same applies to paying money and this depends on whether it should be done now or in the future. Using experts, financial analysis and other methods determine the above weights of the solutions. The weights should be made compatible in two directions: horizontally (among criteria) and vertically (among solutions). In this way, Table 3.7 transforms into a summarized decisionmaking table (Table 3.8) containing all passive house and its components versions and the overall related information.

Stage 12. Determination of passive houses knowledge significances, priorities and utility degree (see Table 3.2). Further, after the formation of decision making matrix (see Table 3.7), the possible most rational versions of a whole passive houses knowledgeare determined and grouped according to their

priority (see stages 1–5). The greater the priority of a version, the higher is the efficiency of the passive houses knowledge.

Table 3.7. Development of passive house knowledge alternatives based on conceptual and quantitative information

The obtained versions of of passive houss	Information related to versions of passive houses							
	Conceptual	Quantitative						
		Cost, X_1 (Lt)	Aesthetics, X_2 (point)	Comfort, X_3 (point)	…	X_j	…	Quality, X_n (point)
1. Windows, A_1	K_1	q_{11}	q_{12}	q_{13}	…	q_{1j}	…	q_{1n}
2. Doors, A_2	K_2	q_{21}	q_{22}	q_{23}	…	q_{2j}	…	q_{2n}
...		...	...	...	…	...	…	...
i. Roofs, A_i	K_i	q_{i1}	q_{i2}	q_{i3}	…	q_{ij}	…	q_{in}
...		...	...	...	…	...	…	...
m. Walls, A_c	K_c	q_{c1}	q_{c2}	q_{c3}	…	q_{cj}	…	q_{cn}

Significance Q_j of a project indicates the satisfaction degree of demands and goals pursued by clients – the greater the Q_j the higher is the efficiency of the passive houses knowledge. In this case, the significance Q_{max} of the most rational project will always be the greatest. The significances of all remaining projects are lower when compared with the most rational one. This means that demands and goals of the stakeholders will be satisfied to a lesser extent than would be the case of the best passive house and its components.

Table 3.8. Summarized decision making table of all passive house and its components versions obtained and the overall related conceptual and quantitative information

The obtained versions of of passive houses	Information related to versions of passive houses							
	Conceptual	Quantitative						
		Cost, X_1 (Lt)	Aesthetics, X_2 (point)	Comfort, X_3 (point)	…	X_j	…	Quality, X_n (point)
1 PR version	K_1	x_{11}	x_{12}	x_{13}	…	x_{1j}	…	x_{1n}
2 PR version	K_2	x_{21}	x_{22}	x_{23}	…	x_{2j}	…	x_{2n}
3 PR version	K_3	x_{31}	x_{32}	x_{33}	…	x_{3j}	…	x_{3n}
...		...	...	...	…	...	…	...
i PR version	K_i	x_{i1}	x_{i2}	x_{i3}	…	x_{ij}	…	x_{in}
...		...	...	...	…	...	…	...
m PR version	K_m	x_{m1}	x_{m2}	x_{m3}	…	x_{mj}	…	x_{mn}
Weights of criteria		q_1	q_2	q_3	…	q_j	…	q_n
Criteria's measuring units		Lt	Points	Points	…	…	…	Points

However, in practice, the customers are more concerned not with the priority of the surveyed passive houses knowledge, but with their utility degree and costs. In other words, a customer is mostly interested in a project that will satisfy its demands and goals to the greatest extent and will be the cheapest and render the least infringement of interests of other parties participating in the project. The results of this assessment are expressed by the project utility degree concept (see Table 3.2).

3.3. Components of the Decision Support System for passive houses knowlegde

Upon analyzing the simulation tools for a passive house or its composite parts (Thiers, Peuportier 2008; Yakubu 1996; Wang, Qiu 2009; Chlela *et al.* 2009; Parker 2009), an Multiple Criteria Decision Support System for Passive Houses Knowledge (DSS-PHK) was developed to design the most efficient versions of a passive houses. The DSS-PHK consists of a developed database, database management system, model-base, model-base management system and user interface (Fig. 3.2).

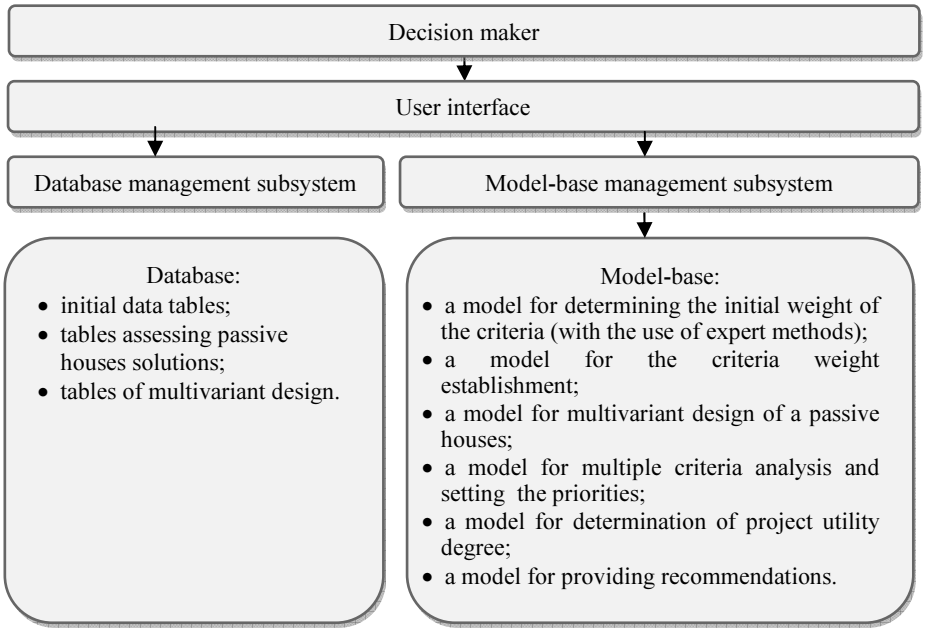


Fig. 3.2. Passive Houses Knowledge System and its composite parts

The following tables comprise the PHK System database:

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

3.3.1. Database management subsystem

The database management system was used to design the structure of a database and perform its completion, storage, editing, navigation, searching, browsing and other functions.

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

The available alternatives should be analysed to design and realise an effective passive houses project. A computer-aided multivariant design requires the availability of the tables containing the data on the interconnections of the elements to be constructed and the solutions, as well as their compatibilities, possible combinations and multivariant design.

Since the objectives and financial situations of PHK 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 contained in the tables. Possible passive house variants are being developed as per the above tables of multivariant passive houses designs. As many as up to 100.000 alternative passive house projects may be obtained by using the multivariant design method

that this author suggests. These project versions are checked for their capacity to meet various requirements. Those that cannot satisfy the requirements raised are excluded from further consideration. Designing a number of passive houses variants causes the problem of the significance compatibility of the criteria. In this case, when a complex evaluation of the alternatives is performed, the value of a criterion weight is dependent on the overall criteria being assessed, as well as on their values and initial weights.

3.3.2. Model-base management subsystem

The methods developed by the Zavadskas and Kaklauskas herein provide the bases for the development of these models as follows (Kaklauskas *et al.* 2006b; Kaklauskas *et al.* 2005):

- A method for the complex determination of criteria weights that takes into account their quantitative and qualitative characteristics, which allows calculating and coordinating the weights of the quantitative and qualitative criteria according to the above characteristics;
- A multiple criteria method for a complex and proportional evaluation of alternatives to enable a student to obtain a reduced criterion for determining the complex (overall) efficiency of an alternative – this generalized criterion is directly proportional to the relative effect of the values and weights of the criteria considered on the efficiency of the alternatives;
- A method to define the utility degree and market value of an alternative by which the utility degree and the market value of the alternatives being estimated are directly proportional to the system of criteria that adequately describes them and the values and weights of such criteria;
- A method for the multiple criteria, multi-variant design of the life cycle of an alternative.

These developed models provide the bases for the ability of an PHK System to generate up to 100.000 passive house alternative versions, perform their multiple criteria analysis, determine their utility degrees and select the most beneficial variant, all without further human intervention.

A management system of the PHK model-base provides a user with a model-base that permits modifying the available models, eliminating those which are no longer needed and adding some new models linked with the existing ones.

The greater the number of alternative versions that are investigated before making a final decision, the greater is the possibility of achieving a more rational end result. The derived information and the PHK System form the bases making it possible to perform a multiple criteria analysis of the composite parts of

passive house and its components projects (walls, windows, roofs, floors, volumetric planning, engineering systems and the like) and to select the most efficient versions. Thereafter the received compatible and rational composite parts of a passive house are joined into projects. The most efficient projects can be selected after performing a multiple criteria analysis of projects generated in such a manner. The strengths and weaknesses of the investigated projects are also analysed. Facts regarding why and to what degree one version is better than another are also established. Conceptual and quantitative information serve as the bases for for accomplishing all this.

Table 3.9. Solar collectors multiple criteria analysis results

Quantitive and qualitative information pertinent to alternatives										
Criteria describing the alternatives	*	Measuring units	Weight	Compared alternatives						
				WATT 3000 S	WATT 4000 S	WATT CPC 9	WATT CPC 15	WATT 3000 SU	WATT 4000 SU	Sveo TS 300
Price	-	LT	0.6	0.0383	0.0596	0.0737	0.1203	0.0892	0.0968	0.0548
Collector's weight	-	kg	0.012	0.0014	0.0014	0.0012	0.002	0.0014	0.0014	0.0014
Volume of liquid in the collector	+	L	0.015	0.0019	0.0019	0.0019	0.0031	0.0017	0	0.0023
Width of transparent surface	+	mm	0.021	0.0022	0.0022	0.003	0.003	0.0022	0.0022	0.003
Area (active) of absorber	+	kv.m.	0.06	0.0069	0.007	0.0072	0.012	0.0069	0.007	0.0066
Efficiency coefficient	-	%	0.031	0.004	0.0044	0.003	0.003	0.004	0.0044	0.0042
Maximum operating pressure	-	Mpa	0.022	0.0039	0.0039	0.0007	0.0007	0.0039	0.0039	0.001
Heat loss coefficient	+	W/kv.m.K	0.052	0.008	0.0086	0.0026	0.0026	0.008	0.0086	0.0067
Maximum solidification temperature	+	C	0.042	0.0048	0.0053	0.0065	0.0065	0.0046	0.0053	0.0041
Warranty	-	year	0.073	0.0087	0.0087	0.0087	0.0087	0.0087	0.0087	0.0104
Durability	-	year	0.061	0.0076	0.0076	0.0076	0.0076	0.0076	0.0076	0.0076
The sums of weighted normalized maximizing (projects "pluses") indices of the alternative				0.025	0.0272	0.0218	0.0283	0.0246	0.0253	0.024
The sums of weighted normalized minimizing (projects "minuses") indices of the alternative				0.0639	0.0856	0.0949	0.1423	0.1148	0.1228	0.0794
Significance of the alternative				0.1723	0.1372	0.121	0.0944	0.1066	0.102	0.1426
Priority of the alternative				1	3	5	8	6	7	2
Utility degree of the alternative (%)				100%	79.62%	70.22%	54.78%	61.87%	59.2%	82.76%

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

The research for this dissertation included an automated multiple criteria analysis of a passive house and its components, such as windows and smart windows, external doors, walls and smart walls, heat recovery ventilators, wind turbines, geothermal boiler houses, roof, and solar collectors. Next, the procedure to measure the weight, utility degree and priority of solar collectors is briefly reviewed as an example (Steps 1–6).

Eight options of solar collectors were subjected to the multiple criteria analysis considering 12 parameters (Table 3.9).

The determination of significance, priority and utility degree of alternatives is carried out in five stages.

Stage 1: The weighted normalized decision making matrix D is formed (see formula 3.2 and Table 3.9). First formula is used for this purpose:

d_{11} = 0.6 × 1540 : (1540 + 2395 + 2962+ 4835 + 3585 + 3889 + 2200 + 2700) = 0.0383,
d_{12} = 0.6 × 2395 : (1540 + 2395 + 2962+ 4835 + 3585 + 3889 + 2200 + 2700) = 0,0596,
d_{13} = 0.6 × 2962 : (1540 + 2395 + 2962+ 4835 + 3585 + 3889 + 2200 + 2700) = 0.0737,
d_{14} = 0.6 × 4835 : (1540 + 2395 + 2962+ 4835 + 3585 + 3889 + 2200 + 2700) = 0.1203,
d_{15} = 0.6 × 3585 : (1540 + 2395 + 2962+ 4835 + 3585 + 3889 + 2200 + 2700) = 0.0892,
d_{16} = 0.6 × 3889 : (1540 + 2395 + 2962+ 4835 + 3585 + 3889 + 2200 + 2700) = 0.0968,
d_{17} = 0.6 × 2200 : (1540 + 2395 + 2962+ 4835 + 3585 + 3889 + 2200 + 2700) = 0.0548,
d_{18} = 0.6 × 2700 : (1540 + 2395 + 2962+ 4835 + 3585 + 3889 + 2200 + 2700) = 0.0672 etc.

The value of significance q_i of the investigated criterion is proportionally distributed among all windows versions o, according to their values x_{ij}. For example:

q_1 = 0.0383+ 0.0596+ 0.0737+ 0.1203+ 0.0892+ 0.0968+ 0.0548+ 0.0672= 0.6000,

q_2 = 0.0014+ 0.0014+ 0.0012+ 0.0020+ 0.0014+ 0.0014+ 0.0014+ 0.0018= 0.0120 etc.

Stage 2: The sums of weighted normalized indexes describ-ing the jth version are calculated. The sums are calculated according to 3.3 and 3.4 formula:

$S_{+1} = 0.0019+0.0016+ 0.0023+ 0.0149+ 0.00003+ 0.0048 = 0.0255,$

$S_{-1} = 0.0383+ 0.0014+0.0040+ 0.0039+ 0.0087+ 0.0076 = 0.0639$ etc.

In any case, the sums of "pluses" S_{+j} and "minuses" S_{-j} of all alternative projects are always, respectively, equal to all sums of the weights of maximizing and minimizing criteria (see formula 3.5 and 3.6):

$S_{+} = 0.0255 +0.0275 +0.0122 +0.0141 +0.0251 +0.0256 +0.0371 +0.0380 =0.205,$

$S_{-} = 0.0639 +0.0857 +0.0949 + 0.1423 + 0.1148 + 0.1228 + 0.0794 + 0.0952 =0.799.$

Stage 3: Relative significance *Qj* of each project o, is found according to 3.7 formula:

$$Q_1 = 0.0255+\frac{0.0639\cdot 0.7990}{0.0639}\times$$

$$\times\frac{1}{\left(\frac{0.0639}{0.0639}+\frac{0.0639}{0.0857}+\frac{0.0639}{0.0949}+\frac{0.0639}{0.1423}+\frac{0.0639}{0.1148}+\frac{0.0639}{0.1228}+\frac{0.0639}{0.0794}+\frac{0.0639}{0.0952}\right)}=$$

$=0.1728,$

$$Q_2 = 0.0275+\frac{0.0639\cdot 0.7990}{0.0857}\times$$

$$\times\frac{1}{\left(\frac{0.0639}{0.0639}+\frac{0.0639}{0.0857}+\frac{0.0639}{0.0949}+\frac{0.0639}{0.1423}+\frac{0.0639}{0.1148}+\frac{0.0639}{0.1228}+\frac{0.0639}{0.0794}+\frac{0.0639}{0.0952}\right)}=$$

$=0.1375,$

$$Q_3 = 0.0122+\frac{0.0639\cdot 0.7990}{0.0949}\times$$

$$\times\frac{1}{\left(\frac{0.0639}{0.0639}+\frac{0.0639}{0.0857}+\frac{0.0639}{0.0949}+\frac{0.0639}{0.1423}+\frac{0.0639}{0.1148}+\frac{0.0639}{0.1228}+\frac{0.0639}{0.0794}+\frac{0.0639}{0.0952}\right)}=$$

$=0.1115$ etc.

Stage 4: The greater the *Qj,* the higher is the efficiency (priority) of the solar collectors alternatives. $Q_1 > Q_2 > Q_8 > Q_7 > Q_3 > Q_5 > Q_6 > Q_4$ (0.1728 >0.1375 >0.1370 >0.1557 >0.1115 >0.1071 >0.1023 >0.0802).

The first version is the best in the utility degree equaling 100%. The seventh version was second according to priority and its utility degree was equal to 90.09%.

Stage 5: 3.8 formula is used for the calculation utility degree N_j:

$N_1 = (0.1728 : 0.1728) \cdot 100\ \% = 100\%,$

$N_2 = (0.1375 : 0.1728) \cdot 100\ \% = 79.53\%,$

$N_3 = (0.1115 : 0.1728) \cdot 100\ \% = 64.50\%$

$N_4 = (0.0802 : 0.1728) \cdot 100\ \% = 46.43\%$

$N_5 = (0.1071 : 0.1728) \cdot 100\ \% = 61.99\%$

$N_6 = (0.1023 : 0.1728) \cdot 100\ \% = 59.19\%$

$N_7 = (0.1557 : 0.1728) \cdot 100\ \% = 90.09\%$

$N_8 = (0.1370 : 0.1728) \cdot 100\ \% = 79.27\%$

The results of a multiple criteria evaluation of five solar collectors versions are presented in Table 3.9. From Table 3.9, it is seen that the first version is the best in the utility degree that equals 100%.

Stage 6: Multiple criteria analysis of solutions dealing with renovation of a thermal unit, roof, walls, entrance door, etc was carried out in a similar way as that of the solar collectors. Further on, we repeated the first five stages till the significance, utility degree and priority of all the passive house and its components were estimated.

3.4 Multivariant design and multiple criteria analysis of the whole passive houses

After the multiple criteria analysis of the life cycle of a passive house and its components (walls, windows, roof, thermal unit, etc) and a selection the most efficient versions, the received compatible and rational components of a refurbishment are joined into the alternatives. Having performed a multivariant design and multiple criteria analysis of the passive house in this way, one can select the most efficient alternatives. Multivariant design and multiple criteria analysis of the whole passive house are carried out in next six stages (stages 7–12).

Stage 7. Rejection of potentially inefficient versions. Further complex multiple criteria analysis of of life cycle of a passive house was based on the four best solution versions that were chosen separately for various components.

Stage 8. The codes of passive house and its components alternative solutions with conceptual and quantitative information (see Table 3.4) have been developed.

Stage 9. Development of passive house and its components alternatives based on codes of solution alternatives. An example formation of the variants (according to their codes) making a complex passive house and its components scheme is given in Table 3.10. In the process of forming possible versions the compatibility of separate variants of complex renovation is taken into account.

Table 3.10. Development of passive house and its components alternatives based on codes of solution alternatives

	The solutions considered	The formation of versions of passive house and its components																		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	...	64	65
1	Windows variants	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	...	4	4
2	Doors variants	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	...	5	3
3	Walls variants	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	...	3	4
4	Smart walls variants	4	4	4	4	3	3	3	3	2	2	2	2	1	1	1	1	...	1	4
5	Recuperators variants	3	1	4	2	3	1	4	2	3	1	4	2	3	1	4	2	...	2	3

Table 3.10. continued

	The formation of versions of passive house and its components																			
	…	123	…	152	…	185	…	277	…	356	…	528	529	…	856	857	…	1023	1024
1	...	4	...	4	...	4	...	3	...	3	...	2	2	...	1	1	...	1	1
2	...	3	...	1	...	1	...	5	...	3	...	5	5	...	3	3	...	2	2
3	…	3	…	1	…	3	…	1	…	2	…	4	1	…	1	1	…	3	3
4	...	2	...	3	...	2	...	3	...	4	...	1	4	...	3	2	...	1	1
5	…	4	…	2	…	3	…	3	…	2	…	2	3	…	2	3	…	4	2

Stages 10 and 11. Development of a summarized decision making table of all passive house and its components versions are obtained. An example of the formation of complex passive house and its components versions and pertinent character-istics is shown in Fig. 3.3. The prepared passive house and its components versions are assessed according to different requirements. A version not corresponding to these reąuirements is stricken out and no longer considered.

Stage 12. Determination of passive house and its components significances, priorities and utility degree.

PRACTICAL TUTORING SYSTEM

LT | EN | RU | [Prisijungti]

System description | Description of alternatives | Results of multiple criteria evaluation of the alternatives | Lentelių sujungimas | Computer-aided development of the feasible alternatives | Multiple criteria analysis of the developed feasible alternatives | Recommendations for user

Calculation time: 12.822832s
Number of possible alternatives: 16329600

Criteria describing the alternatives	*	Measuring units	Weight	Compared alternatives									
				Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 1 Smart Wal Smartenergy GMSW 10 plius FUGA NANOTHECH 730	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 3 Smart Wal Smartenergy GMSW 10 plius FUGA NANOTHECH 730	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 1 Smart Wal Smartenergy GMSW 10 plius KREISEL 131	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 1 SmartWall Systems Smartenergy GMSW 10 plius FUGA NANOTHECH 730	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 3 Smart Wal Smartenergy GMSW 10 plius KREISEL 131	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 3 SmartWall Systems Smartenergy GMSW 10 plius FUGA NANOTHECH 730	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 1 SmartWall Systems Smartenergy GMSW 10 plius KREISEL 131	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 1 Smart Wal Smartenergy SIL1TE FUGA NANOTHECH 730	Baltijos langai MagiGlas Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 1 Smart Wal Smartenergy GMSW 10 plius FUGA NANOTHECH 730	Baltijos
Price	-	Lt/kv.m	0.6	0.000274	0.000274	0.000274	0.000274	0.000274	0.000274	0.000274	0.000274	0.000274	0.000274
Mechanical strength and stiffness	-	Mpa	0.025	1.2E-05	1.2E-05	1.2E-05	1.2E-05	1.2E-05	1.2E-05	1.2E-05	1.2E-05	1.2E-05	1.2E-05
Reliability	-	Cycle	0.026	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06
Heat transfer coefficient of profile	-	W/kv.m.K	0.055	2.3E-05	2.3E-05	2.3E-05	2.3E-05	2.3E-05	2.3E-05	2.3E-05	2.3E-05	2.3E-05	2.3E-05
Heat transfer coefficient of double glazing	-	W/kv.m.K	0.052	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	2.1E-05
Airborne sound		dB	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Fig. 3.3. Formation of complex main passive house and its components versions

System description | Description of alternatives | Results of multiple criteria evaluation of the alternatives | Lentelių sujungimas | Computer-aided development of the feasible alternatives | Multiple criteria analysis of the developed feasible alternatives | Recommendations for user

Criteria describing the alternatives	*	Measuring units	Weight	Compared alternatives									
				Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 1 Smart Wal Smartenergy GMSW 10 plius FUGA NANOTHECH 730	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 3 Smart Wal Smartenergy GMSW 10 plius FUGA NANOTHECH 730	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 1 Smart Wal Smartenergy GMSW 10 plius KREISEL 131	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 1 SmartWall Systems Smartenergy GMSW 10 plius FUGA NANOTHECH 730	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 3 Smart Wal Smartenergy GMSW 10 plius KREISEL 131	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 3 SmartWall Systems Smartenergy GMSW 10 plius FUGA NANOTHECH 730	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 1 SmartWall Systems Smartenergy GMSW 10 plius KREISEL 131	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 1 Smart Wal Smartenergy SIL1TE FUGA NANOTHECH 730	Baltijos langai MagiGlas Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 1 Smart Wal Smartenergy GMSW 10 plius FUGA NANOTHECH 730	Baltijos
Price	-	Lt/kv.m	0.6	0.000274	0.000274	0.000274	0.000274	0.000274	0.000274	0.000274	0.000274	0.000274	0.000274
Mechanical strength and stiffness	+	Mpa	0.025	1.2E-05	1.2E-05	1.2E-05	1.2E-05	1.2E-05	1.2E-05	1.2E-05	1.2E-05	1.2E-05	1.2E-05
Reliability	+	Cycle	0.026	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06
Content of water-soluble chromium VI in dry mix	-	%	0.073	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	3.6E-05
Colour range	-	pcs.	0.061	4.8E-05	4.8E-05	1.2E-05	4.8E-05	1.2E-05	4.8E-05	1.2E-05	4.8E-05	4.8E-05	1.2E-05
Mass	-	kg	0.011	1E-06	1E-06	1E-05	1E-06	1E-05	1E-06	1E-05	1E-06	1E-06	1E-05
Warranty	-	month	0.073	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	3.6E-05
The sums of weighted normalized maximizing (projects 'pluses') indices of the alternative				0.00128	0.00125	0.001277	0.001279	0.001247	0.001249	0.001276	0.001258	0.001291	0.001246
The sums of weighted normalized minimizing (projects 'minuses') indices of the alternative				0.003767	0.003751	0.003774	0.00378	0.003758	0.003764	0.003787	0.003773	0.003805	0.003771
Significance of the alternative				0.00576645	0.00575559	0.00575513	0.00575002	0.0057442	0.00573903	0.00573876	0.00573732	0.00573265	0.0057276
Priority of the alternative				1	2	3	4	5	6	7	8	9	10
Utility degree of the alternative (%)				100%	99.81%	99.8%	99.72%	99.61%	99.52%	99.52%	99.49%	99.41%	99.33%

Fig. 3.4. Determination of passive house and its components significances, priorities and utility degree

The results of the multiple criteria evaluation of the 100 passive house and its components versions are given in Figure 3.4. From the numeric values it can be seen that the 1th version is the best among all the versions that were evaluated. The utility degree of it N_1 = 100%. The 2th version according to its priority was recognized as the second best. The utility degree of it N_2 = 99.81% (see Fig. 3.4).

3.5. Case study

To demonstrate the Passive houses knowledge system in action – and the features of its models and the way they operate its use is described.

To start using the system, a user has to open any web browser installed in the computer.

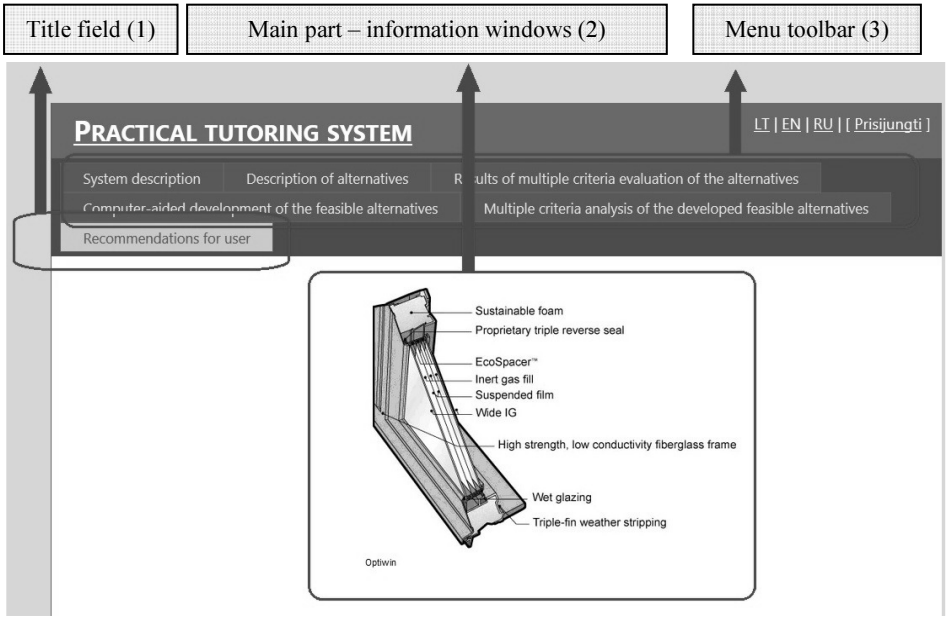


Fig. 3.5. The main window of Passive Houses Knowledge System

The system is best viewed with Internet Explorer, but it runs smoothly on other web browsers too (Opera, Mozilla Firefox and so on). Internet Explorer was used in all the steps and examples discussed below.

The system's main windows consists of three sections (Fig. 3.5):

- title field (1);
- the main part (2);

- menu toolbar (3).

The header shows the system's name; it is a fixed part of the window. The menu bar below the header is also fixed; each menu option activates a certain function when selected.

The menu bar of the recommender passive house and its components system includes the following menu options:

- System description
- Description of 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

The information window shows the graphic view of the system; then comes the system's fixed heading.

Description of the alternatives

A description of working with the PHK System and its operation and functions are presented next.

Fig. 3.6. Fragment of the smart windows graphical database (Умные окна, 2012)

Initially a client who wants to construct a passive house and its components deals with the selection of the best alternatives of windows, roofs, walls, solar collectors, wind generators, geothermic boilers, gas boilers and such. All these

procedures are based both on explicit and tacit knowledge. Smart windows are presented in Figure 3.6 as an example of the graphical database.

Alvarez, Lee and Mahendra (Alvarez *et al.* 2010) note that nanomaterials will likely have a greater impact on the construction industry than any other sector of the economy, after biomedical and electronics applications. They cite dozens of potential applications. For example nanomaterials can strengthen both steel and concrete, keep dirt from sticking to windows, kill bacteria on hospital walls, make materials fire-resistant, drastically improve the efficiency of solar panels, boost the efficiency of indoor lighting and even allow bridges and buildings to "feel" the cracks, corrosion and stress that will eventually cause structural failures (Alvarez *et al.* 2010).

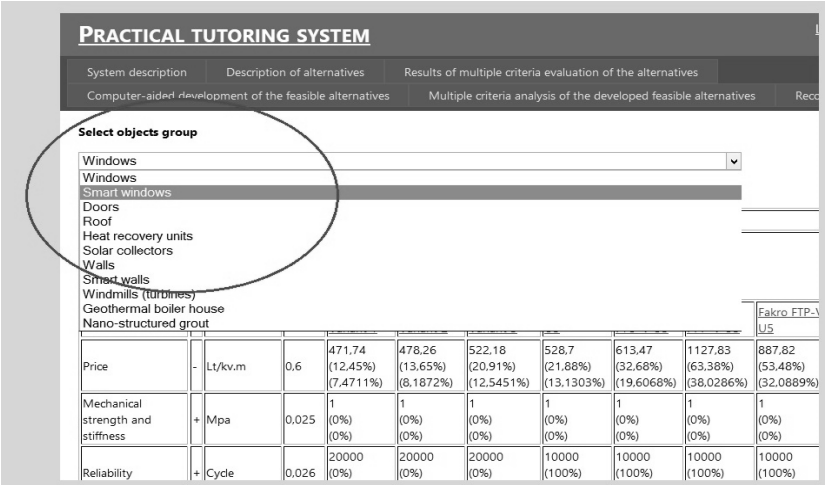


Fig. 3.7. The window of analyzed alternative

Smart windows automatically change tint according to their temperature when using nanotechnology. The idea is simple enough: when it gets hot, the windows darken to block incoming solar radiation and, when it is cold, they are clear to allow the free heat in – all without electricity. The windows use “an organic, nontoxic polymer which changes its molecular structure in response to temperature.” Smart windows can cut a building’s energy use by 30–40% each year. That adds up to a potential, simple payback of six years for the product (Smashcrab... 2010).

Compiled information provided by manufacturers, experts and users comprise the initial quantitative and qualitative database (criteria system, values and weights of criteria) of smart windows, roofs, walls, solar collector, wind generators, geothermic boilers, gas boilers and such.

The mouse is clicked on the items “Description of the alternatives” and “Windows”. Then the system provides the user with the initial data necessary for the analysis (Fig. 3.7). The main data on the compared variants are presented in the form of a decision making matrix: its columns express the discussed alternative variants of windows, and the rows present quantitative information describing the discussed alternatives in detail. In this particular case, nine windows variants are described in detail by 15 criteria for further analysis.

Table 3.11. Initial data of the windows multiple criteria analysis

System description | Description of alternatives | Results of multiple criteria evaluation of the alternatives | Lentelių sujungimas | Computer-aided development of the feasible alternatives | Multiple criteria analysis of the developed feasible alternatives | Recommendations for user

Calculation time: 2.6314313

Select objects group

Windows

Qualitative and quantitative description of the alternatives:

Quantitive and qualitative information pertinent to alternatives												
				Compared alternatives								
Criteria describing the alternatives	*	Measuring units	Weight	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/kv.m	0.6	471.74	478.26	522.18	528.7	613.47	1127.83	887.82	413	656.52
Mechanical strength and stiffness	+	Mpa	0.025	1	1	1	1	1	1	1	1	1
Reliability	+	Cycle	0.026	20000	20000	20000	10000	10000	10000	10000	10000	10000
Heat transfer coefficient of profile	-	W/kv.m.K	0.055	1.2	1.1	1.1	1.4	1.4	1.5	0.97	0.88	1
Heat transfer coefficient of double glazing	-	W/kv.m.K	0.052	1	1.2	0.9	1	1	1	1	0.73	0.72
Airborne sound insulation coefficient, Rw	+	dB	0.04	30	32	32	32	33	32	30	34	31
Air leak, at pressure difference Dp = 50 Pa	-	m^3/(m^2)h	0.011	0.5	0.55	0.6	0.3	0.25	0.42	0.5	0.4	0.35
Light transmittance when OFF, max	-	%	0.015	60	60	60	60	60	60	60	60	60
Light transmittance when OFF, min	+	%	0.015	54	54	54	54	54	54	54	54	54
Light transmittance when ON, max	+	%	0.015	74	74	74	74	74	74	74	74	74
Light transmittance when ON, min	-	%	0.015	68	68	68	68	68	68	68	68	68
Maximum operating temperature	-	C	0.014	50	50	50	60	50	50	60	50	55
Control voltage	+	V	0.018	15	15	15	15	15	15	15	15	15
Colour-change time (glass)	+	sec.	0.018	1	1	1	1	1	1	1	1	1
Electric power consumption	+	V/kv.m.	0.019	8	8	8	8	8	8	8	8	8
Glass thickness	+	mm	0.006	3.55	3.55	4.5	4.5	3.55	3.55	4.5	3.08	3.55
Warranty term	+	year	0.026	5	5	5	10	10	10	10	5	5
Durability	+	year	0.03	50	50	50	50	50	50	50	50	50

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

Multiple criteria analysis of the components of a passive houses

Table 3.11 presents the criteria system, criteria measuring units and values and weights, which describe the discussed window alternatives in detail. A user may view or specify all the alternatives, their criteria and their values and weights. A mouse-click on the title of each discussed variant (criterion) opens a new window on the web-browser, which presents detailed conceptual (textual, photographic) data of the selected variant (criterion).

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

For instance, the calculations determined the utility degree and priority of the available options of windows. The results show *that Baltijos Langai with* the utility degree N_2 = 100% is the best option among those listed in the table, followed by "Megrame, Variant 1" (N_6 = 89.26%), "Megrame, Variant 2" (N_3 = 88.05%), and so on.

The other components of a passive house and its components (doors, roof, solar collectors, etc) are assessed by the multiple criteria analysis likewise. By adding new data to the databases, the variants of other solutions may also be assessed by the multiple criteria analysis.

Table 3.12. Fragment of the windows multiple criteria analysis

System description | Description of 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

Calculation time: 1,5949639s

Select objects group

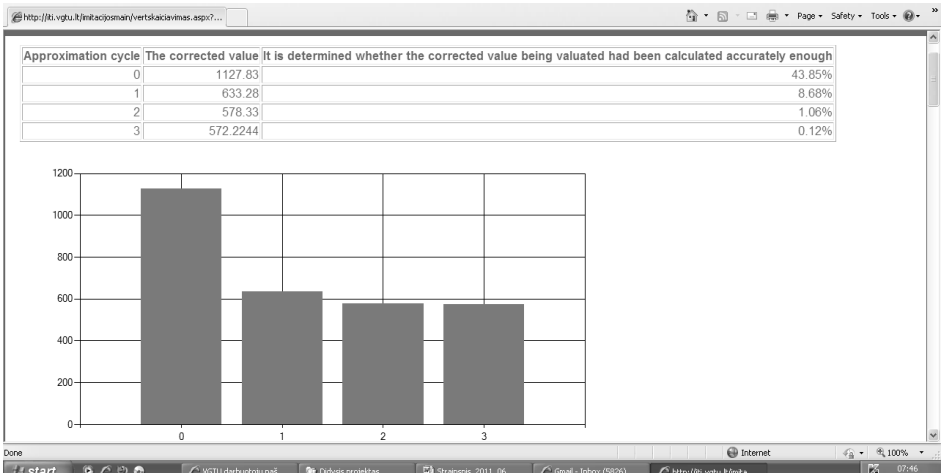
Windows

Quantitive and qualitative information pertinent to alternatives												
Criteria describing the alternatives	*	Measuring units	Weight	Compared alternatives								
				Megrame, Variant 1	Megrame, Variant 2	Megrame, Variant 3	Fakro FTP-V U3	Fakro FTU-V U3	Fakro PPP-V U3	Fakro FTP-V U5	Baltijos langai	Optiwin
Price	-	Lt/kv.m	0,6	0,0497 AVG MIN	0,0503 AVG MIN	0,055 AVG MIN	0,0557 AVG MIN	0,0646 AVG MIN	0,1187 AVG MIN	0,0935 AVG MIN	0,0435 AVG MIN	0,0691 AVG MIN
Mechanical strength and stiffness	+	Mpa	0,025	0,0028 AVG MIN	0,0028 AVG MIN	0,0028 AVG MIN	0,0028 AVG MIN	0,0028 AVG MIN	0,0028 AVG MIN	0,0028 AVG MIN	0,0028 AVG MIN	0,0028 AVG MIN
Reliability	+	Cycle	0,026	0,0043 AVG MIN	0,0043 AVG MIN	0,0043 AVG MIN	0,0022 AVG MIN	0,0022 AVG MIN	0,0022 AVG MIN	0,0022 AVG MIN	0,0022 AVG MIN	0,0022 AVG MIN
Heat transfer coefficient of profile	-	W/kv.m.K	0,055	0,0063 AVG MIN	0,0057 AVG MIN	0,0057 AVG MIN	0,0073 AVG MIN	0,0073 AVG MIN	0,0078 AVG MIN	0,0051 AVG MIN	0,0046 AVG MIN	0,0052 AVG MIN
Heat transfer coefficient of double glazing	-	W/kv.m.K	0,052	0,0061 AVG MIN	0,0073 AVG MIN	0,0055 AVG MIN	0,0061 AVG MIN	0,0061 AVG MIN	0,0061 AVG MIN	0,0061 AVG MIN	0,0044 AVG MIN	0,0044 AVG MIN
Airborne sound insulation coefficient, Rw	+	dB	0,04	0,0042 AVG MIN	0,0045 AVG MIN	0,0045 AVG MIN	0,0045 AVG MIN	0,0046 AVG MIN	0,0045 AVG MIN	0,0042 AVG MIN	0,0048 AVG MIN	0,0043 AVG MIN
[illegible] when ON, min	-	%	0,015	[illegible] AVG MIN	[illegible] AVG MIN	[illegible] AVG MIN	[illegible] AVG MIN	[illegible] AVG MIN	[illegible] AVG MIN	[illegible] AVG MIN	[illegible] AVG MIN	[illegible] AVG MIN
Maximum operating temperature	-	C	0,014	0,0015 AVG MIN	0,0015 AVG MIN	0,0015 AVG MIN	0,0018 AVG MIN	0,0015 AVG MIN	0,0015 AVG MIN	0,0018 AVG MIN	0,0015 AVG MIN	0,0016 AVG MIN
Control voltage	+	V	0,018	0,002 AVG MIN	0,002 AVG MIN	0,002 AVG MIN	0,002 AVG MIN	0,002 AVG MIN	0,002 AVG MIN	0,002 AVG MIN	0,002 AVG MIN	0,002 AVG MIN
Colour-change time (glass)	+	sec.	0,018	0,002 AVG MIN	0,002 AVG MIN	0,002 AVG MIN	0,002 AVG MIN	0,002 AVG MIN	0,002 AVG MIN	0,002 AVG MIN	0,002 AVG MIN	0,002 AVG MIN
Electric power consumption	+	V/kv.m.	0,019	0,0021 AVG MIN	0,0021 AVG MIN	0,0021 AVG MIN	0,0021 AVG MIN	0,0021 AVG MIN	0,0021 AVG MIN	0,0021 AVG MIN	0,0021 AVG MIN	0,0021 AVG MIN
Glass thickness	+	mm	0,006	0,0006 AVG MIN	0,0006 AVG MIN	0,0008 AVG MIN	0,0008 AVG MIN	0,0006 AVG MIN	0,0006 AVG MIN	0,0008 AVG MIN	0,0005 AVG MIN	0,0006 AVG MIN
Warranty term	+	year	0,026	0,002 AVG MIN	0,002 AVG MIN	0,002 AVG MIN	0,004 AVG MIN	0,004 AVG MIN	0,004 AVG MIN	0,004 AVG MIN	0,002 AVG MIN	0,002 AVG MIN
Durability	+	year	0,03	0,0033 AVG MIN	0,0033 AVG MIN	0,0033 AVG MIN	0,0033 AVG MIN	0,0033 AVG MIN	0,0033 AVG MIN	0,0033 AVG MIN	0,0033 AVG MIN	0,0033 AVG MIN
The sums of weighted normalized maximizing (projects 'pluses') indices of the alternative				0,0267	0,027	0,0272	0,0271	0,027	0,0269	0,0268	0,0251	0,0247
The sums of weighted normalized minimizing (projects 'minuses') indices of the alternative				0,0684	0,0698	0,0728	0,0752	0,0836	0,1387	0,1113	0,0585	0,0847
Significance of the alternative				0,1254	0,1237	0,1199	0,1169	0,1077	0,0756	0,0874	0,1405	0,1044
Priority of the alternative				2	3	4	5	6	9	[illegible]	1	7
Utility degree of the alternative (%)				89,26%	88,05%	85,35%	83,21%	76,66%	53,81%	62,21%	100,01%	74,31%

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 3.12).

Determining the market value of the available component alternatives for a passive houses

To ascertain what price will make the alternatives under assessment competitive on the market, the authors suggest a method for determining the utility degree and market value of alternatives, which is based on the complex analysis of all their benefits and drawbacks. According to this method, an alternative's utility degree and its estimated market value are directly proportional to the system of criteria adequately describing them and the values and weights of these criteria. Figure 3.8 presents a fragment of the market value analysis of the Fakro PPP-V U3 window.



Approximation cycle	The corrected value	It is determined whether the corrected value being valuated had been calculated accurately enough
0	1127.83	43.85%
1	633.28	8.68%
2	578.33	1.06%
3	572.2244	0.12%

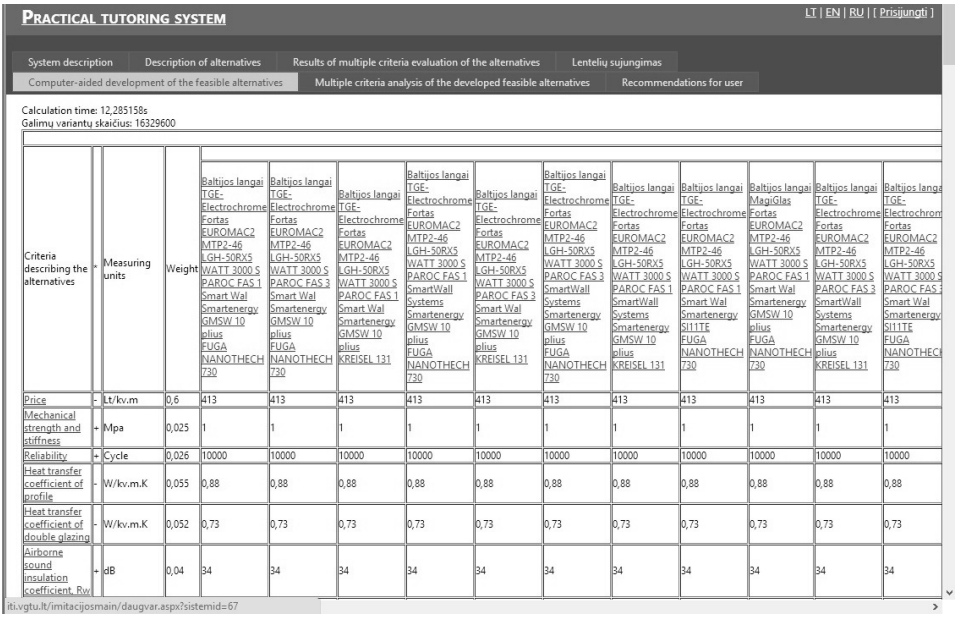
Fig. 3.8. Fragment of the Fakro PPP-V U3 window market value analysis

Take the case of windows and how the value of each option is determined. The system's multiple criteria model for determining the utility degree and a component's value makes an integrated assessment of all minuses and pluses of the alternatives in question, and finds out the price of the alternative in question at which it will be equally competitive in the market. For instance, a price cut from LTL 1.127 to LTL 572 will make windows Fakro PPP-V U3 a fair competitor to the most appealing alternative of the windows, while its utility degree will go up from 53.81% to 79.26% and it will rank sixth in the priority list, up from the ninth position (see Fig. 3.8).

Multiple criteria analysis of the components of a passive houses and multivariant design

Once the multiple criteria analysis is completed on smart windows, roofs, walls, solar collectors, winds generators, geothermic boilers, gas boilers and the like, alternative variants are developed automatically (see Fig. 3.10), and the best alternative combinations are provided. The alternative, multiple criteria variant design method was developed by the authors for this purpose.

A click on the menu option "Computer-aided selection of the most efficient alternatives" displays all components of a passive house (doors, roof, solar collectors, etc) in the main window. The system's user may pick any preferred number and types of alternatives (Fig. 3.9).



Criteria describing the alternatives	+	Measuring units	Weight	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 1 Smart Wal Smartenergy GMSW 10 plius FUGA NANOTHECH 730	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 3 Smart Wal Smartenergy GMSW 10 plius FUGA NANOTHECH 730	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 1 Smart Wal Smartenergy GMSW 10 plius KREISEL 131	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 1 SmartWall Systems Smartenergy GMSW 10 plius FUGA NANOTHECH 730	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 3 Smart Wal Smartenergy GMSW 10 plius KREISEL 131	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 3 SmartWall Systems Smartenergy GMSW 10 plius FUGA NANOTHECH 730	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 1 SmartWall Systems Smartenergy GMSW 10 plius KREISEL 131	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 1 Smart Wal Smartenergy SI11TE FUGA NANOTHECH 730	Baltijos langai MagiGlas Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 1 Smart Wal Smartenergy GMSW 10 plius FUGA NANOTHECH 730	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 3 SmartWall Systems Smartenergy GMSW 10 plius KREISEL 131	Baltijos langa TGE-Electrochrom Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 3 Smart Wal Smartenergy SI11TE FUGA NANOTHEC 730
Price	-	Lt/kv.m	0,6	413	413	413	413	413	413	413	413	413	413	413
Mechanical strength and stiffness	+	Mpa	0,025	1	1	1	1	1	1	1	1	1	1	1
Reliability	+	Cycle	0,026	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
Heat transfer coefficient of profile	-	W/kv.m.K	0,055	0,88	0,88	0,88	0,88	0,88	0,88	0,88	0,88	0,88	0,88	0,88
Heat transfer coefficient of double glazing	-	W/kv.m.K	0,052	0,73	0,73	0,73	0,73	0,73	0,73	0,73	0,73	0,73	0,73	0,73
Airborne sound insulation coefficient, Rw	+	dB	0,04	34	34	34	34	34	34	34	34	34	34	34

Fig. 3.9. Fragment of the computer-aided development of passive houses alternatives

This way the best alternatives are selected. The Passive houses knowledge system, with the help of the multiple criteria analysis and its utility degree models and on the basis of the calculations done theretofore, determines the priority and utility degrees of all available options of the components of a passive house. The next step is the multivariate design which produces a combined set of passive house and its components that meets the needs of stakeholder groups best (Fig. 3.9)

System description | Description of 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

Calculation time: 12,2817592s
Number of possible alternatives: 16329600

Criteria describing the alternatives	*	Measuring units	Weight	Compared alternatives						
				Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 1 Smart Wal Smartenergy GMSW 10 plius FUGA NANOTHECH 730	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 3 Smart Wal Smartenergy GMSW 10 plius FUGA NANOTHECH 730	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 1 Smart Wal Smartenergy GMSW 10 plius KREISEL 131	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 1 SmartWall Systems Smartenergy GMSW 10 plius FUGA NANOTHECH 730	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 3 Smart Wal Smartenergy GMSW 10 plius KREISEL 131	Baltijos langai TGE-Electrochrome Fortas EUROMAC2 MTP2-46 LGH-50RX5 WATT 3000 S PAROC FAS 3 SmartWall Systems Smartenergy GMSW 10 plius FUGA NANOTHECH 730	Baltijos TGE-El Fortas EUROM MTP2-- LGH-5(WATT : PAROC SmartV Smarte GMSW KREISE
Price	-	Lt/kv.m	0,6	0,000274	0,000274	0,000274	0,000274	0,000274	0,000274	0,0002
Mechanical strength and stiffness	+	Mpa	0,025	1,2E-05	1,2E-05	1,2E-05	1,2E-05	1,2E-05	1,2E-05	1,2E-05
Reliability	+	Cycle	0,026	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06	8E-06
Heat transfer coefficient of	-	W/kv.m.K	0,055	2,3E-05	2,3E-05	2,3E-05	2,3E-05	2,3E-05	2,3E-05	2,3E-05

Fig. 3.10. Fragment of the computer-aided development of passive house alternatives

caused by capillary adsorption	+	kg/ (m^2)√min	0,021	9E-06	9E-06	1,1E-05	9E-06	1,1E-05	9E-06	1,1E-05
Combustibility class	+	A	0,052	2,5E-05	2,5E-05	2,5E-05	2,5E-05	2,5E-05	2,5E-05	2,5E-05
Content of water-soluble chromium VI in dry mix	-	%	0,073	3,6E-05	3,6E-05	3,6E-05	3,6E-05	3,6E-05	3,6E-05	3,6E-05
Colour range	-	pcs.	0,061	4,8E-05	4,8E-05	1,2E-05	4,8E-05	1,2E-05	4,8E-05	1,2E-05
Mass	-	kg	0,011	1E-06	1E-06	1E-05	1E-06	1E-05	1E-06	1E-05
Warranty	-	month	0,073	3,6E-05	3,6E-05	3,6E-05	3,6E-05	3,6E-05	3,6E-05	3,6E-05
The sums of weighted normalized maximizing (projects 'pluses') indices of the alternative				0,00128	0,00125	0,001277	0,001279	0,001247	0,001249	0,00127
The sums of weighted normalized minimizing (projects 'minuses') indices of the alternative				0,003767	0,003751	0,003774	0,00378	0,003758	0,003764	0,00378
Significance of the alternative				0,00576645	0,00575559	0,00575513	0,00575002	0,0057442	0,00573903	0,00573
Priority of the alternative				1	2	3	4	5	6	7
Utility degree of the alternative (%)				100%	99,81%	99,8%	99,72%	99,61%	99,52%	99,52%

Fig. 3.11. The best combination priority of the alternative 100%

For instance, the multivariate design revealed that the best combination of passive houses and its components would be Option 1: Baltijos Langai, TGE-Electrochrome, external door Fortas, roof system EUROMAC2, heat recovery ventilation system LGH-50RX5, solar collector WATT 3000S, thermal insulation of walls PAROC FAS1, Smart Wall, wind turbine Smartenergy GMSW10 plus, and nanoputty FUGA Silver 731 (Fig. 3.9).

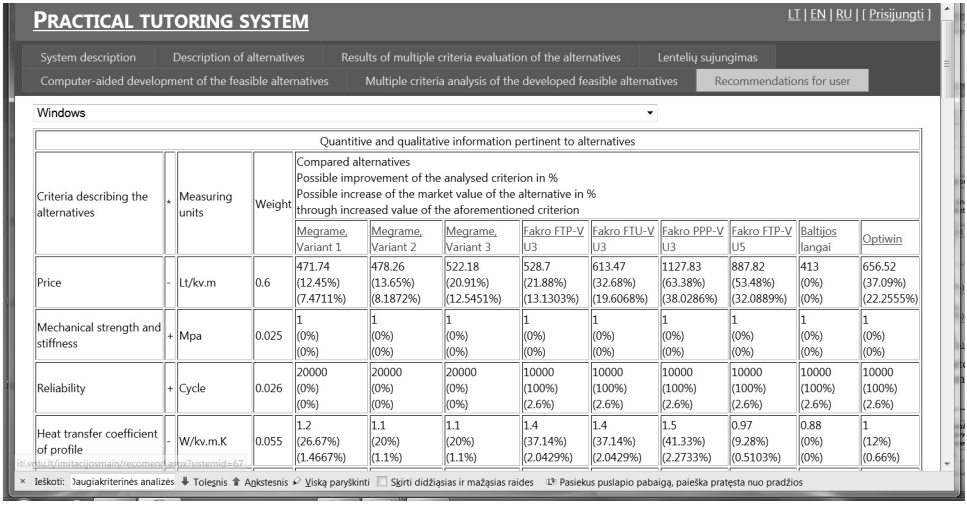
Display of recommendations

The recommender management system of passive houses components offers the following recommendations:

The price of a window Fakro PPP-V U3 is LTL 1,127.83.

The calculations show that, in theory, a cut in the price of this window by about 63% would make the window more appealing compared to other available window options. (PPP-V windows are made from steel-reinforced multi-chambered profiled white PVC and come with an efficient air vent V35P and energy-saving glazing U3. As they are damp-proof and corrosion-proof, these windows are a perfect choice for rooms with high moisture production, such as bathrooms or kitchens.)

A 63% drop in the window's price would make it more appealing by 38%.



PRACTICAL TUTORING SYSTEM

LT | EN | RU | [Prisijungti]

System description | Description of alternatives | Results of multiple criteria evaluation of the alternatives | Lentelių sujungimas

Computer-aided development of the feasible alternatives | Multiple criteria analysis of the developed feasible alternatives | Recommendations for user

Windows

Quantitive and qualitative information pertinent to alternatives

Criteria describing the alternatives	*	Measuring units	Weight	Compared alternatives Possible improvement of the analysed criterion in % Possible increase of the market value of the alternative in % through increased value of the aforementioned criterion								
				Megrame, Variant 1	Megrame, Variant 2	Megrame, Variant 3	Fakro FTP-V U3	Fakro FTU-V U3	Fakro PPP-V U3	Fakro FTP-V U5	Baltijos langai	Optiwin
Price	-	Lt/kv.m	0.6	471.74 (12.45%) (7.4711%)	478.26 (13.65%) (8.1872%)	522.18 (20.91%) (12.5451%)	528.7 (21.88%) (13.1303%)	613.47 (32.68%) (19.6068%)	1127.83 (63.38%) (38.0286%)	887.82 (53.48%) (32.0889%)	413 (0%) (0%)	656.52 (37.09%) (22.2555%)
Mechanical strength and stiffness	+	Mpa	0.025	1 (0%) (0%)	1 (0%) (0%)	1 (0%) (0%)	1 (0%) (0%)	1 (0%) (0%)	1 (0%) (0%)	1 (0%) (0%)	1 (0%) (0%)	1 (0%) (0%)
Reliability	+	Cycle	0.026	20000 (0%) (0%)	20000 (0%) (0%)	20000 (0%) (0%)	10000 (100%) (2.6%)	10000 (100%) (2.6%)	10000 (100%) (2.6%)	10000 (100%) (2.6%)	10000 (100%) (2.6%)	10000 (100%) (2.6%)
Heat transfer coefficient of profile	-	W/kv.m.K	0.055	1.2 (26.67%) (1.4667%)	1.1 (20%) (1.1%)	1.1 (20%) (1.1%)	1.4 (37.14%) (2.0429%)	1.4 (37.14%) (2.0429%)	1.5 (41.33%) (2.2733%)	0.97 (9.28%) (0.5103%)	0.88 (0%) (0%)	1 (12%) (0.66%)

Ieškoti: Daugiakriterinės analizės | Toleęnis | Aąkstesnis | Viską paryškinti | Skirti didžiąsias ir mažąsias raides | Pasiekus puslapio pabaigą, paieška pratęsta nuo pradžios

Fig. 3.12. Fragment of recommendations for passive house window

With this in mind, it is possible to solve the problem of optimization concerning satisfaction of the needs at reasonable expenditures. This requires the analysis of criteria allowing to find an optimal combination of different interested parties' goals pursued and finances available. As example, Fig. 3.12 provides extensive information about the quantitative effect of criteria on market value of passive house and its components. Each cell of this table shows three numbers:

- The numerical value of the analyzed criterion;
- Possible improvement of the analyzed criterion in %;

Megrame, Variant 1			
Position	***Criteria describing the alternatives***	***Possible improvement of the analysed criterion in %***	***Possible increase of the market value of the alternative in % through increased value of the aforementioned criterion***
1	Price	12,45%	7,4711%
2	Warranty term	100%	2,6%
3	Heat transfer coefficient of profile	26,67%	1,4667%

Megrame, Variant 2			
Position	***Criteria describing the alternatives***	***Possible improvement of the analysed criterion in %***	***Possible increase of the market value of the alternative in % through increased value of the aforementioned criterion***
1	Price	13,65%	8,1872%
2	Warranty term	100%	2,6%
3	Heat transfer coefficient of double glazing	40%	2,08%

Megrame, Variant 3			
Position	***Criteria describing the alternatives***	***Possible improvement of the analysed criterion in %***	***Possible increase of the market value of the alternative in % through increased value of the aforementioned criterion***
1	Price	20,91%	12,5451%
2	Warranty term	100%	2,6%
3	Heat transfer coefficient of profile	20%	1,1%

Fakro FTP-V U3			
Position	***Criteria describing the alternatives***	***Possible improvement of the analysed criterion in %***	***Possible increase of the market value of the alternative in % through increased value of the aforementioned criterion***
1	Price	21,88%	13,1303%
2	Reliability	100%	2,6%
3	Heat transfer coefficient of profile	37,14%	2,0429%

Fakro FTU-V U3			
Position	***Criteria describing the alternatives***	***Possible improvement of the analysed criterion in %***	***Possible increase of the market value of the alternative in % through increased value of the aforementioned criterion***
1	Price	32,68%	19,6068%
2	Reliability	100%	2,6%
3	Heat transfer coefficient of profile	37,14%	2,0429%

Fakro PPP-V U3			
Position	***Criteria describing the alternatives***	***Possible improvement of the analysed criterion in %***	***Possible increase of the market value of the alternative in % through increased value of the aforementioned criterion***
1	Price	63,38%	38,0286%
2	Reliability	100%	2,6%
3	Heat transfer coefficient of profile	41,33%	2,2733%

Fakro FTP-V U5			
Position	***Criteria describing the alternatives***	***Possible improvement of the analysed criterion in %***	***Possible increase of the market value of the alternative in % through increased value of the aforementioned criterion***
1	Price	53,48%	32,0889%
2	Reliability	100%	2,6%
3	Heat transfer coefficient of double glazing	28%	1,456%

Baltijos langai			
Position	***Criteria describing the alternatives***	***Possible improvement of the analysed criterion in %***	***Possible increase of the market value of the alternative in % through increased value of the aforementioned criterion***
1	Reliability	100%	2,6%
2	Warranty term	100%	2,6%
3	Air leak, at pressure difference Dp = 50 Pa	37,5%	0,4125%

Optiwin			
Position	***Criteria describing the alternatives***	***Possible improvement of the analysed criterion in %***	***Possible increase of the market value of the alternative in % through increased value of the aforementioned criterion***
1	Price	37,09%	22,2555%
2	Reliability	100%	2,6%
3	Warranty term	100%	2,6%

Fig. 3.13. Providing recommendations by Passive Houses Knowledge System

- Possible increase of the market value of the alternative in % through increased value of the aforementioned criterion.

Hence, Fig. 3.13 gives explicit intermediate information about the influence of each criterion on the market value of the analyzed alternative. Traditional analysis methods do not facilitate such explicit analysis of factors affecting an alternative's market value. The DSS-PHK system developed on the basis of multiple criteria analysis methods, which were created by the author of this research, allows to eliminate drawbacks of the traditional analysis and assessment methods, to take a new perspective on the assessment process, to improve objectiveness in determination of pluses and minuses for each alternative and also to validate the market value of alternatives.

Window profiles may also be analysed. Windows and doors are made from profile systems by different manufacturers; the systems mostly differ by their cross-sections, internal structure, sealing, surfaces, aesthetic features, and available functions:

- In case of the window FTU-V U3, the thermal transmittance rate of its profile is 1.4 W/m^2K.
- The calculations show that after some improvements of the profile, if possible, a 37% change of the thermal transmittance rate might be expected and the window's appeal to the client would go up by 2%.

The examples show that the system's recommendations are of benefit both to designers (help pick out the best alternatives) and regular users (help determine the features that need improvements to increase the appeal of the object on offer).

To make the system efficient, a wide range of information is used. Registered users of the PHK system may easily add new values of the factors or change the existing ones, taking heed of their designer's priorities or building on the results of an expert survey. A range of limitations may be set to restrict the available alternatives of passive house and its components.

Other criteria may be considered as well. Each user, in view of his needs and goals, performs calculations, at the same time generating information for other users.

The Passive houses knowlegde system is universal and may be a handy tool to address a range of theoretical and practical problems. The system's features may therefore be useful to organisations in charge of construction projects, various educational institutions, service providers, consultants, experts, end users and other stakeholder groups.

3.6. Conclusions from Chapter 3

1. Researchers considering methods of multiple criteria analysis did not include the topic of the research object by the author, i.e. passive houses knowledge complex analysis and decision making, the stakeholders involved in the project and micro, mezzo and macro environment factors affecting it as an integral whole. Methods of multiple criteria analysis and multi-variant design were applied to the research object.
2. A method of complex determination of the significance of the criteria taking into account their quantitative and qualitative characteristics was adapted. This method allows to calculate and coordinate the significances of the quantitative and qualitative criteria according to the above characteristics.
3. A method of multiple criteria complex proportional evaluation of the projects enabling the user to obtain a reduced criterion determining complex (overall) efficiency of the project was adapted. This generalized criterion is directly proportional to the relative effect of the values and significances of the criteria considered on the efficiency of the project.
4. A method of multiple criteria multivariant design of a passive house and its components life cycle enabling the user to make computer-aided design of up to 100.000 alternative project versions was adapted. Any passive house and its components life cycle variant obtained in this way is based on quantitative and conceptual information
5. In order to find what price will make an object 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. According to this method the objects utility degree and the market value of an object being estimated are directly proportional to the system of the criteria adequately describing them and the values and significances of these criteria.
6. The analysis of information, expert and decision support system used in construction which were developed by researchers from various countries helped the author to create multiple criteria decision support systems of his own. The system developed by the author in cooperation with his colleagues differ from others in the use of new original methods and the object of investigation (presented in Chapter 2). Developed Multiple Criteria Decision Support System for Passive Houses Knowledge is based on the analysis of existing information, knowledge, experts' opinions and analysis of decision support systems, whilst integrating different elements suggested by the author of this thesis and

others working in this field. This System is comprised of three parts: database and database management subsystem, model base and model base management subsystem, and user interface.

7. Numbers contained in the results of this research obtained during testing of the multiple criteria decision support system for passive houses knowledge. It is a universal system and may be applied addressing various theoretical and practical problems, therefore the possibilities provided by this system might be useful to a range of stakeholders (architectural designers, clients, contractors, project managers, users, etc).
8. Passive houses 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 and its components projects by means of quantitative and qualitative forms.
9. Complex databases of a passive houses and its components were developed providing a comprehensive assessment of alternative versions from economic, technical, qualitative, technological, legislative and other perspectives. Based on the above complex databases, the developed decision support system enabling the user to analyze passive house quantitatively (a system and subsystems of criteria, units of measure, values and significances) and conceptually (text, formula, schemes, graphs, diagrams, video tapes) was created.

General conclusions

1. The analysis of technical, technological, management, cultural, social, political, economic and other aspects attitudes towards the construction of energy-efficient buildings in a number of countries leads to a conclusion that researchers look into these criteria mostly in isolation. Integration of all criteria into a single system would produce a more comprehensive description of a life cycle and components of a passive house.
2. Analysis of global research shows that existing passive houses models do not permit for alternative multi-variant design of passive houses and multiple criteria analysis. Analysis of projects and articles by different researchers suggests that they often focus on a single narrow field, such as assessments of the thermal transmittance rate of windows, walls or roofs, energy saving, etc. A passive houses knowledge model and the model's solution methods should therefore be developed.
3. An original model of a complex analysis of a passive houses knowledge enabling the user to analyze a passive houses life cycle and its stages, the parties involved in the project as well as its micro, mezzo and macro environments as an integral whole is developed. Passive houses knowledge model is developed on the basis of complex systems theory and the models of the multiple criteria analysis. Model includes the six stages: (1) comparative description of the passive houses knowledge; (2) comparison of the passive houses knowledge and trends; (3) multiple

criteria analysis of the components of passive houses and selection of most efficient components; (4) development of general recommendations; (5) submission of certain recommendations to stakeholders; (6) transformational learning and changing of mental and practical behavior. The model of passive houses knowledge was verified in operational conditions and supports its viability.

4. Researchers considering methods of multiple criteria analysis did not include the topic of the research object by the author, i.e. passive houses knowledge complex analysis and decision making, the stakeholders involved in the project and micro, mezzo and macro environment factors affecting it as an integral whole. Methods of multiple criteria analysis and multi-variant design were applied to the research object.
5. Passive houses complex database was compiled, integrally describing alternatives from the technical, qualitative, security, functionality, technological point of view and other aspects. On the basis of this complex database, database management subsystem and model-base management subsystem, a decision support system was developed, allowing for complex analysis of passive houses quantitatively (system of criteria and its subsystem, measuring units, appraisals, valuations) and conceptually (text, formula, schemes, graphs, diagrams, video tapes).
6. Developed Multiple Criteria Decision Support System for Passive Houses Knowledge is based on the analysis of existing information, knowledge, experts' opinions and analysis of decision support systems, whilst integrating different elements suggested by the author of this thesis and others working in this field. This System is comprised of three parts: database and database management subsystem, model base and model base management subsystem, and user interface.
7. On the basis of the model on a complex analysis of a passive houses knowledge proposed by the author and the methods of multiple criteria analysis and multi-variant design the Multiple Criteria Decision Support System for Passive Houses Knowledge was developed and tested. The system allows evaluation of passive house alternatives, composition of rational alternative selections of passive house components, establishing level of their efficacy, utility degree (eg., N_{Op1} – 100%, N_{Op2} – 99.81%, …, N_{Op100} – 97.6%), market value, and eventually making the right decision in automated way. It is a universal system and may be applied addressing various theoretical and practical problems, therefore the possibilities provided by this system might be useful to a range of stakeholders (architectural designers, clients, contractors, project managers, users, etc).

References

Afgan, N. H.; Carvalho, M. G. 2002. Multi-criteria assessment of new and renewable energy power plants, *Energy* 27: 739–755.

Alanne, K.; Salo, A.; Saari, A.; Gustafsson, S. I. 2007. Multicriteria evaluation of residential energy supply systems, *Energy and Buildings* 39(12):1218–1226.

Alvarez, P.; Lee, J.; Mahendra, S. 2010. Safety of Nanomaterials That Will Soon Have a Big Impact on the Construction Industry, Science Daily, July 28.

Asadi, E.; Silva, M. G.; Antunes, C. H.; Dias, L. 2012. A multi-objective optimization model for building retrofit strategies using TRNSYS simulations, GenOpt and MATLAB, *Building and Environment* 56: 370–378.

Badescu, V. 2007a. Economic aspects of using ground thermal energy for passive house heating, *Renewable Energy* 32(6): 895–903.

Badescu, V. 2007b. Simple and accurate model for the ground heat exchanger of a passive house, *Renewable Energy* 32(5): 845–855.

Badescu, V.; Laaser, N.; Crutescu, R.; Crutescu, M.; Dobrovicescu, A.; Tsatsaronis, G. 2011. Modeling, validation and time-dependent simulation of the first large passive building in Romania, *Renewable Energy* 36(1): 142–157.

Badescu, V.; Staicovici, M. D. 2006. Renewable energy for passive house heating model of the active solar heating system, *Energy and Buildings* 38(2): 129–141.

Beccali, M.; Cellura, M.; Ardente, D. 1998. Decision making in energy planning: The ELECTRE multicriteria decision analysis approach compared to a fuzzy-sets methodology, *Energy Conversion Management* 39 (16–18): 1869–1881.

Beccali, M.; Cellura, M.; Mistretta, M. 2003. Decision-making in energy planning. Application of the Electre method at regional level for the diffusion of renewable energy technology, *Renewable Energy* 28: 2063–2087.

Berggren, B.; Hall, M.; Wall, M. 2013. LCE analysis of buildings – Taking the step towards Net Zero Energy Buildings, *Energy and Buildings* 62: 381–391.

Brandt, E.; Rasmussen, M. H. 2002. Assessment of building conditions, *Energy and Buildings* 34(2): 121–125.

Brossard, D.; Scheufele, D. A.; Kim, E.; Lewenstein, B. V. 2009. Religiosity as a perceptual filter: Examining processes of opinion formation about nanotechnology, *Public Understanding of Science*, 18: 546–568.

Cavallaro, F.; Ciraolo, L. 2005. A multicriteria approach to evaluate wind energy plants on an Italian island, *Energy Policy*, 33: 235–244.

Cellura, M.; Di, Gangi, A.; Longo, S; Orioli, A. 2013. An Italian input–output model for the assessment of energy and environmental benefits arising from retrofit actions of buildings, *Energy and Buildings* 62: 97–106.

Chen, S. J.; Hwang, C. L. 1992. Fuzzy Multiple Attribute Decision Making: Methods and Applications, *Lecture Notes in Economics and Mathematical Systems*, No. 375, Sringer-Verlag, Berlin, Germany.

Chlela, F.; Husaunndee, A.; Inard, C.; Riederer, P. 2009. A new methodology forthe design of low energy buildings, *Energy and Buildings* 41: 982–990.

Danny, H. W. Li; Yangb, Liu; Joseph, C. Lam. 2013. Zero energy buildings and sustainable development implications – A review, *Energy* 54: 1–10.

Davey, I. 2009. Environmentalism of the Poor and Sustainable Development: An Appraisal, *Journal of Administration and Governance* 4(1): 1–10.

Decker, D. J.; Siemer, W. F.; Evensen, D. T. N.; Stedman, R. C.; McComas, K. A.; Wild, M. A.; Castle, K. T.; Leong, K. M. 2012. Public perceptions of wildlife-associated disease: risk communication matters, *Human Wildlife Interactions* 6(1): 112–122.

Dessai, S.; Adger, W. N.; Hulme, M.; Turnpenny, J.; Kohler, J.; Warren, R. 2004. Defining and experiencing dangerous climate change, *Climatic Change* 64(1–2): 15

Diakaki, C.; Grigoroudis, E.; Kabelis, N.; Kololotsa, D.; Kalaitzakis, K. 2010. A multi-objective decision model for the improvement of energy efficiency in buildings, *Energy* 35: 5483–5496.

Diakaki, C.; Grigoroudis, E.; Kolokotsa, D. 2008. Towards a multi-objective optimization approach for improving energy efficiency in buildings, *Energy and Buildings* 40(9): 1747–1754.

Diakoulaki, D.; Zopounidis, C.; Mavrotas, G.; Doumpos, M. 1999. The use of a preference disaggregation method in energy analysis and policy making, *Energy* 24: 157–166.

Dioguardi, G. F. 1983. Macrofirm: Construction firms for the computer age, Journal of Construction Engineering and Management, *ASCE* 109: 13–24.

Eccles, R. G. 1981b. The quasi-firm in the construction industry, *Journal of Economic Behavior and Organization* 2: 521–529.

Elsarrag, E.; Alhorr, Y. 2012. Modelling the thermal energy demand of a Passive-House in the Gulf Region: The impact of thermal insulation, *International Journal of Sustainable Built Environment* 1: 1–15.

Emerson, J.; Esty, D. C.; Levy, M. A.; Kim, C. H.; Mara, V. 2010. de Sherbinin A.; Srebotnjak T.. Environmental Performance Index. *New Haven: Yale Center for Environmental Law and Policy.*

Energy Saving Potential. 2006. *Promotion of European Passive Houses*. Intelligent Energy Europe Programme. Project No. EIE/04/030/S07.39990

Fernandes, N. T. A.; Costa, V. A. F. 2009. Use of phase-change materials as passive elements for climatization purposes in summer: The Portuguese case, *International Journal of Green Energy.* 6(3): 302–311.

Filippín, C.; Flores Larsen, S.; Lopez, Gay, E. 2008. Energy improvement of a conventional dwelling in Argentina through thermal simulation, *Renewable Energy* 33(10): 2246–2257.

Flourentzou, F.; Roulet, C.-A. 2002. Elaboration of retrofit scenarios, *Energy and Buildings* 34: 185–192.

Franzen, A.; Meyer, R. 2010. Environmental Attitudes in Cross-National Perspective: A Multilevel Analysis of the ISSP 1993 and 2000, *European Sociological Review* 26(2): 219–234.

Gamboa, G.; Munda, G. 2007. The problem of windfarm location: A social multicriteria evaluation framework, *Energy Policy* 35: 1564–1583.

Georges, L.; Massart, C.; Van Moeseke, G.; De Herde, A. 2012. Environmental and economic performance of heating systems for energy-efficient dwellings: Case of passive and low-energy single-family houses, *Energy Policy* 40: 452–464.

Georgopoulou, E.; Lalas, D.; Papagiannakis, L. 1997. A Multicriteria Decision Aid approach for energy planning problems: The case of renewable energy option, *European Journal of Operational Research* 103: 38–54.

Gero, J. S.; Neville, D. C.; Radford, A. D. 1983. Energy in context: a multi-criteria model for building design, *Building and Environment* 18(3): 99–107.

Goodacre, C.; Sharples, S.; Smith, P. 2002. Integrating energy efficiency with the social agenda in sustainability, *Energy and Buildings* 34(1): 53–61.

Goumas, M. G.; Lygerou, V. A.; Papayannakis, L. E. 1999. Computational methods for planning and evaluation geothermal energy projects, *Energy Policy* 27: 147–154.

Griffiths, M.; Brooks, D. J. 2012. Informing Security Through Cultural Cognition: The Influence of Cultural Bias on Operational Security, *Journal of Applied Security Research* 7(2): 218–238.

Guha, R.; Martínez-Alier, J. 1997. *Varieties of Environmentalism, Earthscan,* London.

Halse, A. 2005. Passive houses in Norway. *Innovation systems, social and ecological change.* 2004–2005. University of Oslo/Aalborg University.

Haralambopoulos, D. A.; Polatidis, H. 2003. Renewable energy projects: structuring a multi-criteria group decision-making framework, Renewable Energy 28: 961–973.

Hasselaar, E. 2006. Health performance of housing, indicators and tools, Amsterdam: IOS, Press under the imprint of Delft University Press, PhD thesis, 298 p.

Hasselaar, E. 2008. Health risk associated with passive houses: An exploration, *Indoor Air* 17–22.

Ho, S. S.; Brossard, D.; Scheufele, D. A. 2008. Effects of value predispositions, mass media use, and knowledge on public attitudes toward embryonic stem cell research, *International Journal of Public Opinion Research* 20: 171–192.

Inglehart, R. 1995. Public Support for Environment Protection: Objective Problems and Subjective Values in 43 Societies, *Political Science and Politics* 28: 57–72.

Inglehart, R. 1997. Princeton University Press, Princeton, *Modernization and Postmodernization* 43: 440.

Inglehart, R.; Welzel, C. 2005. Cambridge University Press, Cambridge, Modernization, Cultural Change and Democracy , *The Human Development Sequence* 1–18.

Jaber, J. O.; Jaber, Q. M.; Sawalha, S. A.; Mohsen, M. S. 2008. Evaluation of conventional and renewable energy sources for space heating in the household sector. Renewable and Sustainable, *Energy Reviews* 12(1): 278–289.

Jaggs, M.; Palmar, J. 2000. Energy performance indoor environmental quality retrofit a European diagnosis and decision making method for building refurbishment, *Energy and Buildings* 31: 97–101.

Juan, Y.-K.; Kim, J. H.; Roper, K.; Lacouture, D. C. 2009. GA-based decision support system for housing condition assessment and refurbishment strategies, *Automation in Construction* 18: 394–401.

Kablan, M. M.; 2004. Decision support for energy conservation promotion: An analytic hierarchy process approach, *Energy Policy* 32: 1151–1158.

Kahan, D. M.; Slovic, P.; Braman, D.; Gastil, J.; Cohen, G.; Kysar, D. 2008. Biased assimilation, polarization and cultural credibility: An experimental study of nanotechnology risk perceptions, in Research Brief No. 3.

Kaklauskas, A.; Gulbinas, A.; Krutinis, M; Naimavičienė, J.; Šatkauskas, G. 2007a. Mokymo procese naudojamų pasirenkamųjų modulių daugiavariantės analizės metodai, *Ūkio technologinis ir ekonominis vystymas* 10(3): 253–258.

Kaklauskas, A.; Naimavičienė J.; Kanapeckienė L.; Tupėnaitė L. 2007b. Knowledge base model for sustainable housing renovation, *The 9th International Conference Modern Building Materials, Structures and Technique*, 276–281.

Kaklauskas, A.; Zavadskas, E. K. 2002a. *Internetinė sprendimų parama: monografija*. Vilnius: Technika. 216 p.

Kaklauskas, A.; Zavadskas, E. K.; Ditkevičius, R. 2006b. An intelligent tutoring system for construc-tion and real estate, *Lecture Notes in Computer Science* 4101: 174–181.

Kaklauskas, A.; Zavadskas, E. K.; Raslanas, S. 2005. Multivariant design and multiple criteria analysis of building refurbishments, *Energy and Buildings* 37(4): 361–372.

Kaklauskas, A.; Zavadskas, E. K.; Raslanas, S.; Ginevičius, R.; Komka, A.;. Malinauskas, P. 2006a. Selection of low-e windows in retrofit of public buildings by applying multiple criteria method COPRAS: A Lithuanian case, *Energy and Buildings* 38(5): 454–462.

Kaklauskas, A.; Zavadskas, E. K.; Vainiūnas, P. 2001. Efficiency Increase of real estate e-business systems by applying multiple criteria decision support systems, in *ERES 2001: Eighth European real estate society conference*: Alicante, June 26–29, 2001: proceedings [CD]. University of Alicante, 11–24

Kaklauskas, A.; Zavadskas, E. K.; Vainiūnas, P.; Trinkūnas, V. 2002b. Construction calculators, analyzers, software, experts and decision support systems, their integration and applications, in *ISEC 2002: Second International Conference on Information Systems in Engineering and Construction*. Department of Construction Management University of Nebraska Lincoln, 8–18.

Karlsson, J. F.; Moshfegh, B. 2006. Energy demand and indoor climate in a low energy building – changed control strategies and boundary conditions, *Energy and Buildings* 38(4): 315–326.

Kaynakli, O. 2012. A review of the economical and optimum thermal insulation thickness for building applications, *Renewable and Sustainable Energy Reviews* 16: 415–425.

Kumar, R.; Sachdeva, S.; Kaushik, S. C. 2007. Dynamic earth-contact building: a sustainable low-energy technology, *Building and Environment* 42(6): 2450–2460.

Kusuda, T. 2001. Building environment simulation before desk top computers in the USA through a personai memory, *Energy and Buildings* 33(4): 291–302.

Lang, G. 2009. International Passivhaus Database, *Establishment of a Co-operation Network of Passive House Promoters (PASS-NET).*

Leiserowitz, A. A. 2005. American risk perceptions: Is climate change dangerous?, *Risk Analysis* 25(6): 1433–1442.

Løken, E. 2007. Use of multicriteria decision analysis methods for energy planning problems. Renewable and Sustainable, *Energy Reviews* 11(7):1584–1595.

Macias, M.; Gaona, J. A.; Luxan, J. M.; Gomez, G. 2009. Low cost passive cooling system for social housing in dry hot climate, *Energy and Buildings* 44(9): 915–921

Malckzewski, J. 1999. *GIS and Multicriteria Decision Analysis.* Wiley, New York.

Martinez-Alier, J. 1995. The environment as a luxury or “too poor to be green”?, *Ecological Economics* 13: 1–10.

Martinez-Alier, J. 2000. Environmental Justice as a Force for Sustainability, in: J. Pieterse, ed. *Global Futures: Shaping Globalization*, Zed Books, New York, pp. 148–174.

Mirasgedis, S.; Diakoulaki, D. 1997. Multicriteria analysis vs. externalities assessment for the comparative evaluation of electricity generation systems, *European Journal of Operational Research* 102: 364–379.

Mlecnik, E.; Schütze, T.; Jansen, S. J. T.; De Vries, G.; Visscher, H. J.; Van Hal, A. 2012. End-user experiences in nearly zero-energy houses, *Energy and Buildings* 49: 471–478.

Mlecnik, E., Marrecau, C. 2008. Passive house projects in Belgium, *International Journal of Environmental Technology and Management* 9(4): 390–401

Murphy, L. 2012. Building Regulations for Energy Conservation, *International Encyclopedia of Housing and Home*. 110–116.

Nagesha, N.; Balachandra, P. 2006. Barriers to energy efficiency in small industry clusters: multi-criteria-based prioritization using the analytic hierarchy process, *Energy* 31(12): 1969–1983.

Nigim, K.; Munier, N.; Green, J. 2004. Pre-feasibility MCDM tools to aid communities in prioritizing local viable renewable energy sources, *Renewable Energy* 29: 1775–1791.

NorthPass Project IEE/08/480/SI2.528386. Deliverable D13. Country-specific market analysis, success factors, marketing approach, and market situation.

Osmani, M, O'Reilly, A. 2009. Feasibility of zero carbon homes in England by 2016: A house builder's perspective, *Building and Environment* 44: 1917–1924.

Parker, D. S. 2009. Very low energy homes in the United States: perspectives on performance from measured data, *Energy and Buildings* 41(5): 512–520.

Paschoalique, C. V.; Macho, K. 2009. Unfired industrial loam brick buildings with passive house standard [Lehmziegel-Gebäude mit Passivhaus-Standard]. ZI, *Ziegelindustrie International/Brick and Tile Industry International.* (1–2): 18–27

Pathirage, C. P.; Amaratunga, R. D. G.; Haigh, R. P. 2006. Managing Tacit Knowledge for Enhancing Performance in the Construction Industry. Bibliographic details: RICS (COBRA 2006). London. ISBN: 9781842193074.

Peuportier, B.; Thiers, S.; Guiavarch, A. 2013. Eco-design of buildings using thermal simulation and life cycle assessment, *Journal of Cleaner Production* 39: 73–78.

Rapp, A. B. 2008. Lean workflows and best energy parameters wall and floor units for passive houses built "in a single cast" [Schlanke arbeitsabläufe und beste energiewerte wand- Und deckenelemente für passivhäuser "aus einem guss"], *Betonwerk und Fertigteil-Technik/Concrete Plant and Precast Technology* 75(11): 58–61

Renn, O. 2003. Social assessment of waste energy utilization scenarios, *Energy* 28: 1345–1357.

Rey, E. 2004. Office building retrofitting strategies: multicriteria approach of an architectural and technical issue, *Energy and Buildings* 36: 367–372.

Saaty, T. L. 2001. Fundamentals of decision making and priority theory with the Analytic Hierarchy Process. RWS Publications, Pittsburgh.

Salo, A. A.; Hämäläinen R. P. 1992. Preference assessment by imprecise ratio statements, *Operations Research* 40(6): 1053–1061.

Saporito, A.; Day, A. R.; Karayiannis, T. G.; Parand, F. 2001. Multi-parameter building thermal analysis using the lattice method for globai optimisation, *Energy and Buildings* 33(3): 267–274.

Scheufele, D. A. 2006. Messages and heuristics: How audiences form attitudes about emerging technologies, in Engaging Science: Thoughts, Deeds, *Analysis and Action* (ed. Turney, J.), The Wellcome Trust, London, pp. 20–25.

Scheufele, D. A.; Lewenstein, B. V. 2005. The public and nanotechnology: How citizens make sense of emerging technologies, *J. Nanopart. Res.* 7: 659–667.

Schnieders, J. 2006. Climate Data for the Determination of Passive house Heat Loads in Northwest Europe. PEP Project Information.

Schnieders, J.; Hermelink, A. 2006. CEPHEUS results: measurements and occupants' satisfactions provide evidence for Passive houses being an option for sustainable building, *Energy Policy* 34(2): 151–171.

Science, technology and innovation, *Eurostat regional yearbook*, 2011.

Slovic, P. 2000. *The Perception of Risk*, London, Earthscan.

Soares, N.; Costa, J. J.; Gaspar, A. R.; Santos, P. 2013. Review of passive PCM latent heat thermal energy storage systems towards buildings' energy efficiency, *Energy and Buildings* 59: 82–103.

Thiel, T.; Mroz, T. 2001. Application of Multi-Criterion Decision Aid method in designing heating systems for museum buildings, *Informatica* 12(1): 133–146.

Thiers, S.; Peuportier, B. 2008. Thermal and environmental assessment of a passive building equipped with an earth-to-air heat exchanger in France, *Solar Energy* 82(9): 820–831.

Triantaphyllou, E.; Shu B.; Nieto Sanchez S.; Ray T. 1998. Multi-Criteria Decision Making: An Operations Research Approach. *Encyclopedia of Electrical and Electronics Engineering*, (J.G. Webster, Ed.), John Wiley & Sons, New York, NY, 15: 175–186.

Tzikopoulos, A. F.; Karatza, M. C.; Paravantis, J. A. 2005. Modeling energy efficiency of bioclimatic buildings, *Energy and Buildings* 37(5): 529–544.

Valeriani, S. 2007. Building on the page – Building on the Site: Christopher Wren's Italian Sources, in *Invited paper at the conference "Enquiry, Evidence and Facts",* December 13–14, London.

Van de Vliert, E.; Tol, R. S. J. 2011. Local Warming, Local Economic Growth, and Local Change in Democratic Culture, *Working Paper No. 378.*

Van de Vliert, E. 2008. Climatoeconomic Roots of Survival Versus Self-Expression Cultures, *Journal of Cross-Cultural Psychology* 38: 156–172.

Van den Bergh, J. C. J. M. 2013. Environmental and climate innovation: Limitations, policies and prices, *Technological Forecasting and Social Change* 80: 11–23.

Venckus, N.; Bliūdžius, R.; Endriukaityte, A.; Parasonis, J. 2010. Research of low energy house design and construction opportunities in Lithuania, *Technological and Economic Development of Economy* 16(3): 541–554.

Venckus, N.; Bliūdžius, R.; Poderytė, J.; Burlingis, A. 2012. The heating load determination of low energy buildings in northern climate, *Journal of Civil Engineering and Management* 18(6): 828–833.

Wang, L.; Gwilliam, J. 2009a. Case study of zero energy house design in UK, *Energy and Buildings* 41: 1215–1222.

Wang, Q.; Qiu, H.-N. 2009. Situation and outlook of solar energy utilization in Tibet, China, *Renewable and Sustainable Energy Reviews* 13(8): 2181–2186.

Wright, J. A.; Loosemore, H. A.; Farmani, R. 2002. Optimization of building thermal design and control by multi-criterion genetic algorithm, *Energy and Buildings* 34(9): 959–972.

Yakubu, G. S. 1996. The reality of living in passive solar homes: a user-experience study, *Renewable Energy* 8: 177–181.

Zadeh, L. A. 1965. Fuzzy sets, *Information and Control* 8: 338–353.

Zavadskas, E. K. 1987. Multiple criteria evaluation of technologica decisions of construction: Dissertation of Dr Sc (in Russian). *Moscow Civil Engineering Institute*, Moscow.

Zavadskas, E. K.; Kaklauskas, A. 1994. Determining the most profitable investment projects. *Zeszyty naukowe Politechniki Poznanskiej*, Budownictwo Ląndowe, Nr. 38. pp. 39–45.

Zavadskas, E. K.; Kaklauskas, A. 1996a. Determination of an efficient contractor by using the new method of multicriteria assessment // Intern. Symposium for "The Organisation and Management of Construction". *Shaping Fhery and Practice.* Vol 2. Managing the Construction Project and Managing Risk. Edited by D.A.Langford and A.Retik CIB W 65. E and FN SPON, London, 94–104.

Zavadskas, E. K.; Kaklauskas, A. 1996b. The new method of multicriteria evaluation of projects // Deutsch-Litauisch-Polnisches Kolloquium zum Baubetriebswesen. Hochschule für Technik, Wirtschaft und Kultur in /Leipzig. 3 Jahrgang. *Sonderheft* 1/96. 3–8.

Zavadskas, E. K.; Kaklauskas, A. 1996c. *Pastatų sistemotechninis įvertinimas* (Multiple criteria evaluation of buildings). Vilnius: Technika, 280 p. (in Lithuanian).

Zavadskas, E. K.; Kaklauskas, A. 1999. New method of complex evaluation of projects based on multiple criteria analysis and the principle of proportionality, in: D.K. Despotis, C. Zopounidis (Eds.), Integrating Technology & Human Decisions: Global Bridges into the 21st Century, vol. II, *Proceedings of the 5th International Conference*, Athens, Greece, pp. 2051–2053.

Zavadskas, E. K.; Kaklauskas, A.; Banaitis, A.; Jonaitis, V. 1998. Creation of rational entrepreneurship conditions in construction industry of Lithuania, *Statyba* 4(1): 78–85.

Zavadskas, E. K.; Kaklauskas, A.; Brzezinski, J. 1995. *Expert systems in construction. Trends, potential & applications.* Vilnius: Technika, 180 p.

Zavadskas, E. K.; Kaklauskas, A.; Raslanas, S.; Krūtinis, M. 2004. Pecularities of multi-criteria e-trade system application in real estate sector, *Journal of Civil Engineering and Management* 10 (Suppl. 1): 71–78.

Zavadskas, E. K.; Kaklauskas, A.; Vainiūnas, P.; Kutut, V.; Turskis, Z. 2003. Nekilnojamojo turto sektoriaus internetinių sistemų efektyvumo didinimas taikant daugiakriterines paramos sistemas, *Journal of Civil Engineering and Management* 9(2): 83–90.

Zavadskas, E. K.; Kaklauskas, A; Raslanas, S. 2005. Multivariant design and multiple criteria analysis of building refurbishments*, Energy and Buildings* 37(4): 361–372.

Zavadskas, E. K.; Sloan, B.; Kaklauskas, A. 1996d. Europos statybos pramonės daugiakriterinė kompleksinė analizė ir Centrinės bei Rytų Europos šalių ateities prognozės, *Vadyba* 4(8): 68–73.

Żelazna, A.; Pawłowski, A. 2011. The Environmental Analysis of Insulation Materials in the Context of Sustainable Buildings, Environmental Engineering, *The 8th International Conference "Environmental Engineering"*, May 19–20, Vilnius, Lithuania, Selected papers, 825–829.

Zmeureanu, R.; Fazio, P.; DePani, S.; Calla, R. 1999. Development of an energy rating system for existing houses, *Energy and Buildings* 29(2): 107–119.

Web links:

Buildings and the Passive house. 2010. [online], Available from Internet: <http://www.polyurethanes.org/index.php?page=buildings-and-the-passive-house>. [accessed 23 09 2012].

Canadian Passive house Institute. 2011. [online], Available from Internet: <http://passivehouse.ca>. [accessed 01 05 2011].

Construction Projects. Smith House. 2002-2003. [online], Available from Internet: <http://www.e-colab.org/ecolab/SmithHouse.html>. [accessed 11 04 2011].

Unities and Local Government, Definition of zero carbon homes and non-domestic buildings. Crown Copyright, London, 2008. ISBN: 978-1-4098-0934-0. [online], Available from Internet: <http://www.zerocarbonhub.org/resourcefiles/1101177.pdf>. [accessed 08 08 2013].

Energy Union. 2010. [online], Available from Internet: <http://www.energyunion.eu /en/blog/passive_house_conference>. [accessed 11 05 2010].

List of International Weather for Energy Calculations 1.1. 2011. [online], Available from Internet: <https://www.trane.com/Commercial/DesignAnalysis/Weather.aspx?i=2094> [accessed 06 08 2013].

Multi-criteria analysis: a manual. 2009. Department for Communities and Local Government: London. [online], Available from Internet: <https://www.gov.uk/ government/uploads/system/uploads/attachment_data/file/7612/1132618.pdf>. [accessed 01 09 2013].

Nation Ranking. 2011. [online], Available from Internet: <http://nationranking. wordpress.com/2011/03/06/2011-rankings>. [accessed 06 03 2011].

Pasyvus būstas su įprastinėmis statybinėmis medžiagomis atsieina nepigiai. 2009. [online], Available from Internet: <http://www.technologijos.lt/n/technologijos/ statybos/straipsnis?name=straipsnis-5898&l=2>. [accessed 14 02 2009].

Passive House Institue. 2010. What can be a passive house in your region with your climate? [online], Available from Internet: <http://www.passiv.de/07_eng/index_e. html>. [accessed 12 08 2013].

PEST Analysis. 2013. [online], Available from Internet: <http://www.marketingteacher. com/lesson-store/lesson-pest.html#>. [accessed 21 02 2013].

Smashcrab. 2010. [online], Available from Internet: <http://smashcrab.org/news/new-window-changes-tint-automatically-when-it-gets-hot>. [accessed 04 11 2010].

The next Passive house Conference will take place at Nuernberg 2008 April 11th and 12th. News about the 12th conference will be available on this site in just a few weeks. [online], Available from Internet: <http://www.passivhaustagung.de /elfte/english/01_start_home.html>. [accessed 24 07 2010].

US Housing and the Passive Home Standard. 2009. [online], Available from Internet: <http://campfire.theoildrum.com/node/4946>. [accessed 14 10 2012].

Wikipedia. Complex systems, 2009c. [online], Available from Internet: http://en.wikipedia.org/wiki/Complex_systems>. [accessed 12 06 2013].

Willis, R. 2007. The future is disruptive, [online], Available from Internet: <http://www.forumforthefuture.org/greenfutures/articles/future-is-disruptive>. [accessed 14 05 2013].

Умные окна. 2012. [online], Available from Internet: <http://www.absolut-company.ru/tge.html>. [accessed 19 09 2013].

The List of Scientific Author's Publications on the Subject of the Dissertation

In the reviewed scientific periodical publications

Kaklauskas, A.; Rutė, J.; Zavadskas, E. K.; Daniūnas, A.; Pruskus, V.; Bivainis, J.; Gudauskas, R.; Plakys, V. 2012. Passive house model for quantitative and qualitative analyses and its intelligent system, *Energy and Buildings* 50: 7–18. ISSN 0378-7788 (Thomson Reuters ISI Web of Science), doi: 10.1016/j.enbuild.2012.03.008

Kaklauskas, A.; Rutė, J.; Gudauskas, R.; Banaitis, A. 2011. Integrated model and system for passive houses multiple criteria analysis, *International Journal of Strategic Property Management* 15(1): 74–90. ISSN 1648-715X (print), ISSN 1648-9179 (online) (Thomson Reuters ISI Web of Science), doi:10.3846/1648715X.2011.574903

Rutė, J. 2011. Išreikštinės ir neišreikštinės žinios pasyviųjų namų statyboje, žinių modeliai pasaulyje ir Lietuvoje, *Mokslas – Lietuvos ateitis* 3(2): 12–16. ISSN 2029-2341 (print), 2029-2252 (online) (Index Copernicus), doi:10.3846/mla.2011.024

Matuliauskaitė, A.; Bartkienė, L.; Rutė, J. 2011. Penki didieji faktoriai ir jų taikymo kryptys, *Mokslas – Lietuvos ateitis* 3(4): 43–48. ISSN 2029-2341 (print), 2029-2252 (online) (Index Copernicus), doi:10.3846/mla.2011.068

In the other editions

Rutė, J.; Bartkienė, L.; Matuliauskaitė, A. 2010. Pasyviųjų būstų koncepcijos raida pasaulyje ir Lietuvoje: skirtumai ir tendencijos, *7-osios mokslinės konferencijos „Technologijos mokslo darbai Vakarų Lietuvoje“ straipsnių rinkinys.* Klaipėda: Klaipėdos universiteto leidykla, 409–412. ISSN 1822-4652.

Jevgenija RUTĖ

KNOWLEDGE MODEL AND MULTIPLE CRITERIA DECISION SUPPORT SYSTEM FOR PASSIVE HOUSES

Doctoral Dissertation

Technological Sciences,
Civil Engineering (02T)

Jevgenija RUTĖ

PASYVIŲJŲ NAMŲ ŽINIŲ MODELIS IR DAUGIAKRITERĖ SPRENDIMŲ PARAMOS SISTEMA

Daktaro disertacija

Technologijos mokslai,
statybos inžinerija (02T)

2013 11 15. 9,5 sp. l. Tiražas 20 egz.
Vilniaus Gedimino technikos universiteto
leidykla „Technika“,
Saulėtekio al. 11, 10223 Vilnius,
http://leidykla.vgtu.lt
Spausdino UAB „Ciklonas“,
J. Jasinskio g. 15, 01111 Vilnius