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VGTU Laboratory Building

CREDIT Case LT01

Danish Building Research Institute
AALBORG UNIVERSITY

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Construction and Real Estate -
Developing Indicators for Transparency

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Preface

This report describes the results of a case study undertaken as part of the Nordic/Baltic project *CREDIT: Construction and Real Estate – Developing Indicators for Transparency*. The case study is part of the work in work package 4-6 with respect to project assessment tools, application in firms and national benchmarking systems.

CREDIT includes the most prominent research institutes within benchmarking and performance indicators in construction and real estate, namely SBi/AAU (Denmark), VTT (Finland), Lund University (Sweden) and SINTEF (Norway). Further, three associated partners have joined CREDIT. The three associated partners are the Icelandic Center for Innovation (Iceland), Tallinn University of Technology (Estonia) and Vilnius Gediminas Technical University (Lithuania).

The project has been managed by a steering committee consisting of the following persons:
– Kim Haugbølle, SBi/AAU (project owner).
– Niels Haldor Bertelsen, SBi/AAU (project coordinator)
– Pekka Huovila, VTT.
– Päivi Hietanen, Senate Properties
– Ole Jørgen Karud, SINTEF.
– Magnus Hvam, SKANSKA.
– Bengt Hansson, Lund University.
– Kristian Widén, Lund University.

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Danish Building Research Institute, Aalborg University
Department of Construction and Health
August 2010

Niels-Jørgen Aagaard
Research director

Summary

This case study has been chosen:
- To show how deficiencies and building damages can be registered one year and five years after the construction has been completed and handed over.
- To analyse the extent of the cost of repairing work.
- To explore how experiences from inspections of finished buildings can be utilized in new construction and as benchmarking.

The Danish Building Defects Fund is the primary source of information on the building quality of Danish non profit housing. The Fund is an independent organization, which was established by law in 1986 as part of a quality and liability reform the same year. Further information can be found on www.byggeskadefonden.dk

Since 1986 it has been obligatory for new housing with public financial support to register at the Fund and pay 1 % of the building costs including site costs to the Fund. A part of the payment is used for inspections – one year and five years after handing over. The rest is an insurance concerning defects.

Buildings (WP4) summary

The inspections are executed in accordance with a general classification of the different parts of a building. They are the indicators. When a deficiency or a building damage is observed, the actual part is therefore also marked. The Fund has furthermore established a classification of the seriousness of a deficiency or a building damage with a division into five categories.

The indicators are the starting point to show whether there are or could be problems with indicators at higher levels as indoor environment (as safety and indoor climate) and product performance (as constructions and installations).

Enterprises (WP5) summary

The indicators are used, as described, when an independent company execute an inspection after hand over. In this way they are not used in the planning or construction of the actual project. But they are used in eventually repair work and in the operation of the building. And due to the dissemination of information and the rules for the obligatory quality assurance they are part of the planning and execution of coming projects.

With one year and five year inspections after hand over it has been possible to establish a rapid and effective feedback of knowledge and experiences concerning building methods, components and materials.

National benchmarking (WP6) summary

The purpose off the Fund is:
- To carry out the one year and five year building inspections
- To give financial support to the repair of building defects
- To communicate findings and experiences about the building process and building to the building sector for the purpose of preventing future buildings defects and to promote quality and efficiency in building.

The information about the quality of housing projects is available in the Fund's extensive database. The database includes all information collected from systematic five year building inspections, which were established in 1991. After 1998 a one year building inspection was established. The information collected here is also stored in the database, and are accessible for the public on www.byggeskadefonden.dk.

The Fund has carried out inspections of approximately 10.000 buildings with approximately 205.000 dwellings in all since 1986. The building inspections register for all parts of the building, which are essential for the lifetime of the building, whether the building part is in accordance with laws, regulations and likely, or if there is defect or damage.

For example all building parts concerning the climate protection are registered, while for instance indoor equipment is not registered, because it has no influence on the lifetime of the building.

Approximately 250 independent firms, consultants (architects and engineers) and other (i.e. contractors) carry out the buildings inspections throughout the country. The same firms are involved in planning, supervision and execution of publicly subsided housing – but of cause they do not carry out inspections of houses, in which they have taken part in the building.

The Fund covers up to 95% of the expenditures for damage repairs, that are claimed at the latest 20 years after hand over has taken place. After acknowledgement of a building damage, the Fund make liability claims to the responsible builder, consultants, contractors and suppliers as far as are possible.

The Fund has developed an extensive statistic about defects in housing, which is disseminated to the industry and clients. The statistic is organized in accordance with different aspects as client (with concrete name), building parts after the classification and seriousness and involved companies (with names).

If necessary the Fund will also publish warnings about specific methods, components or materials. Some examples are problems with stability of buildings, use of specific bricks and cement slates and roofs with light underroofing.

It is estimated that dissemination of information has reduced repair costs by at least 100 million DDK per year. The number of estates with defects has been reduced from about 30 % to about 4 %.

In 2008 the Danish Parliament issued a law concerning private housing in accordance with which it is obligatory for a developer or contractor to sign an insurance concerning possible defects in new dwellings. The law is based on experiences from the Fund, and the Fund is also involved in disseminating knowledge and experiences from this arrangement in order to prevent future buildings defects and to promote quality and efficiency in this type of buildings.

1. Introduction

This chapter describes the objectives of the CREDIT project, the background, scope and purpose of the case study of renovation of VGTU Laboratory Building, and the research design of the study.

1.1 Objectives and work packages of CREDIT

To design and achieve effective life cycle of a building a complex analysis of its stages as well as interested parties, their aims and potentialities is needed. The effect of micro and macro environmental factors should also be taken into account. A building life cycle consists of seven closely interrelated stages: brief, design, construction, maintenance, facilities management, demolition and utilisation. A building life cycle may have a lot of alternative versions. These variants are based on the alternative brief, design, construction, maintenance, facilities management and other processes and their constituent parts. The above solutions and processes may be further considered in more detail. For instance, the alternative building variants may be developed by varying its three-dimensional planning, as well as structural and engineering solutions. Thus, dozens of thousands of building life cycle alternative versions can be obtained. The diversity of solutions available contributes to more accurate evaluation of traditions, climatic conditions, risk exposure, maintenance services, as well as making the project cheaper and better satisfying a client's architectural, comfortability, technological and other requirements. This also leads to better satisfaction of the needs of all parties involved in the project design and realization.

Various interested parties (clients, users, architects, designers, utilities engineers, economists, contractors, maintenance engineers, building material manufacturers, suppliers, contractors, finansing institutions, local government, state and state institutions) are involved in the life cycle of a building, trying to satisfy their needs and affecting its efficiency. The above needs or objectives embrace the expected cost of a building, maintenance costs, living space, number of floors as well as the requirements to its architecture, aesthetics, comfortability, functionality, proportions, materials, sound insulation of partition walls, taxes and allowances, interest rates, etc. Besides, the environment of the site, its ecology, sound level and local infrastructure are also taken into consideration. This list may be continued.

The level of the efficiency of life cycle of a building depends on a number of variables, at two levels: micro and macro level. The efficiency of the life cycle of a building depends on the influence of many complex macro level factors (policy executed by the government, legal and institutional infrastructure, physical infrastructure, financial sector, environment issues, unemployment, interest rate, inflation, innovations, exchange rate). The efficiency level will, therefore, vary depending on the aggregate effect of these macro level factors.

The efficiency level of the life cycle of a building also depends on various micro level factors (sources of company finance, information system of construction, types of contracts, construction employers associations, education and training, brief, designing, manufacture, construction and maintenance processes, etc.) some of which depend on the influence of the macro level factors. For instance, the system of taxation which is set at the macro level (following fiscal policy of the government), exerts a direct influence on wages and salaries (and thereby disposable incomes) and on prices of materials at the micro level (project level). The standpoint of the State (various laws and decrees, working of State institutions, etc.) regarding certain activities exert considerable influence on the efficiency of organizations. The relations of various interested parties (for instance, between customer and contractor) are directly governed by law.

The problem is how to define an efficient building life cycle when a lot of various parties are involved, the alternative project versions come to hundreds thousand and the efficiency changes with the alterations in the environment conditions and the constituent parts of the process in question. Moreover, the realization of some objectives seems more rational from the economic perspective thought from the other perspectives they have various significance. Therefore, it is considered that the efficiency of a building life cycle depends on the rationality of its stages as well as on the ability to satisfy the needs of the interested parties and the rational character of environment conditions.

Formalized presentation of the research shows how changes in the environment and the extent to which the goals pursued by various interested parties are satisfied cause corresponding changes in the value and utility degree of a building life cycle. 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 building life cycle versions allowing find an optimal combination of goals pursued and finances available.

1.2 Background, purpose and focus of the case study

This case study has been chosen

- To capture end user needs and requirements in order to identify and quantify – where possible – value creation in the renovation of VGTU Laboratory Building.
- To develop multiple criteria and quality of life analysis methods.
- To define and develop energy efficiency, quality of life and other indicators for building renovation.
- To explore how the experiences are used in renovation of VGTU Laboratory Building and as benchmarking.

VGTU, who is in charge of the inspections, has developed multiple criteria and quality of life analysis methods; energy efficiency, quality of life and other indicators for building renovation.

1.3 Research design and methods applied in the case study

The present case study is described in the three levels in CREDIT information model: Building level (WP4), VGTU level (WP5) and National benchmarking level (WP6). Multiple criteria and quality of life analysis methods developed by author of this Report are applied in this study as follows:

- A new method of complex determination of the weight of the criteria taking into account their quantitative and qualitative characteristics was developed. This method allows calculate and coordinate the weights of the quantitative and qualitative criteria according to the above characteristics.
- A new 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 suggested. This generalized criterion is directly proportional to the relative effect of the values and weights of the criteria considered on the efficiency of the project.

- 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 weights of these criteria.
- A new method of multiple criteria multivariant design of a building refurbishment enabling the user to make computer-aided design of up to 100,000 alternative refurbishment versions was developed. Any building refurbishment variant obtained in this way is based on quantitative and conceptual information.

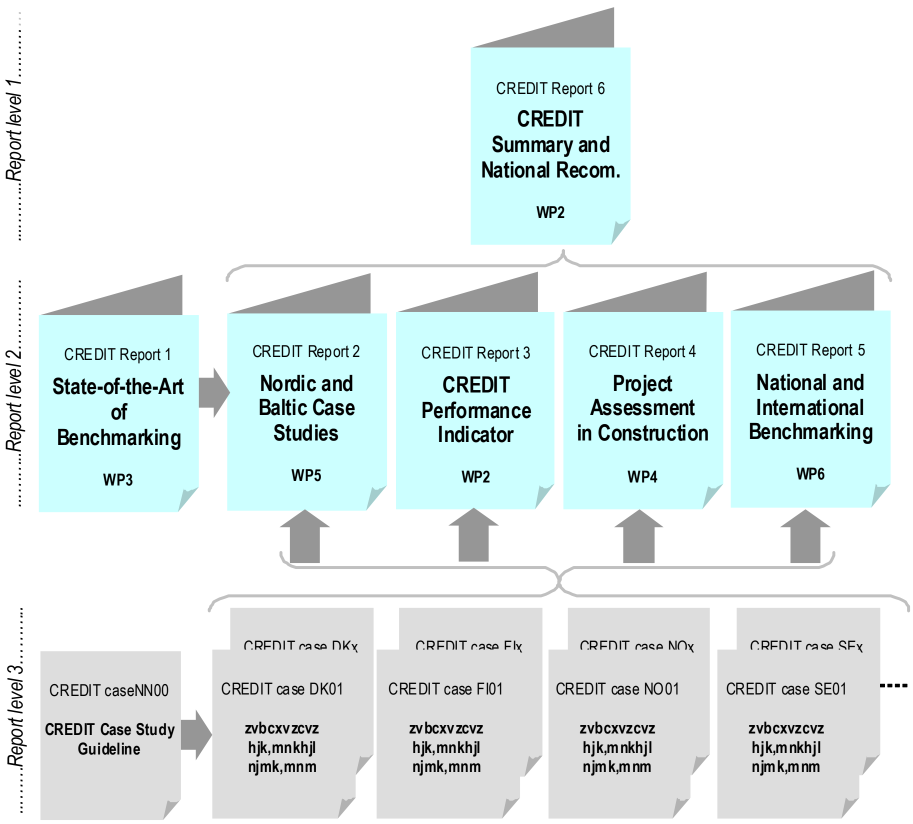
The case study has been written by VGTU.

1.4 Reading instruction

This report summarises the case study of VGTU Laboratory Building as input to work package 4-6 of the CREDIT project. Chapter 2 in this report addresses issues relevant to WP4 on assessments at project level. Chapter 3 addresses issues relevant to WP5 on the application of assessments in firms. Chapter 4 addresses issues relevant to WP6 on sectoral, national or international benchmarking systems. Chapter 5 discusses and concludes on the lessons learned with respect to the three levels of projects, firms and systems.

The work of each work package (WP) is documented in various other reports, articles etc. Below, a graphical illustration of the hierarchy and linkages between the individual reports is given.

Figure 1. Graphical illustration of the hierarchy of the CREDIT reports.



2. Buildings – assessments in construction or real estate processes

The established energy efficiency and quality of life indicators for building renovation (see Appendix 2) are evaluated to define energy efficiency of building refurbishment and quality of life evaluation after completion.

The results concerning the indicators can be used in new housing projects.

The evaluations are executed by local VGTU experts (researchers, teachers). VGTU researchers and professors take initiative to considerable exchange of the results via bachelor and master degree courses, lifelong learning, distance learning and articles.

2.1 The actual building, building parts and processes

The actual case study has focus on refurbishment of a Laboratory Building of Vilnius Gediminas Technical University (VGTU) and evaluation of its energy efficiency and quality of life after renovation. The actual building is situated in Vilnius. Vilnius is located in the southeast of the country. The site of the Laboratory Building of VGTU is suburban. The surrounding of VGTU are Vilnius University, residential housings and forest. VGTU Laboratoric Building was built up in 1971. It includes several departments and lecture halls. Number of occupants – 1084, number of rooms – 219. VGTU Laboratoric Building was built up in 1971. The renovation was finished in 2004.

2.2 The applied assessment methods and tools in the processes

The energy saving (U-value (W/m²K), heating energy consumption (kWh/m²)), quality of life (particle pollution, electromagnetic pollution, illumination, volume flow, air velocity, air temperature, relative humidity, dew point temperature, vibration impulse amplitudes) and refurbishment efficiency (price of refurbishment, etc.) indicators are used, before renovation and when local VGTU experts execute an inspection after hand over (see Appendix 2). In this way the refurbishment efficiency indicators (see Appendix 2) are used in the planning of the actual project. The energy saving and quality of life indicators are used in eventually repair work and in the operation of the building. And due to the dissemination of information they can be a part of the planning and execution of coming projects.

Multiple criteria and quality of life analysis methods developed by author of this Report are applied in the analysis of the above indicators:

- A new method of complex determination of the weight of the criteria taking into account their quantitative and qualitative characteristics was developed. This method allows calculate and coordinate the weights of the quantitative and qualitative criteria according to the above characteristics.
- A new 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 suggested. This generalized criterion is directly proportional to the relative effect of the

values and weights of the criteria considered on the efficiency of the project.
- 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 weights of these criteria.
- A new method of multiple criteria multivariant design of a building refurbishment enabling the user to make computer-aided design of up to 100,000 alternative refurbishment versions was developed. Any building refurbishment variant obtained in this way is based on quantitative and conceptual information.

Above methods mostly are used in case studies for final bachelor, master or PhD thesis. Web-based Building's Refurbishment Knowledge and Devices Based Decision Support System (BR-KD-DSS) developed by our Department (Department of Construction Economics and Property Management)consist of a database, database management system, model-base, model-base management system, devices, facilities management, market value analysis, premise's microclimate, pollution, human emotions analysis subsystems and a user interface. Therefore, only one hour is needed to employ above methods and System. The application above methods and BR-KD-DSS have been described in the Appendix 2.

Above methods and System can be used by end user, client, investor, architect/engineer, contractor, manufacturer, seller, buyer, researcher or impartial third part.

VGTU local experts developed the system of energy saving, quality of life and refurbishment efficiency indicators. Above indicators are reflecting needs of different VGTU stakeholders (investors, administration, teaching personal, students, etc.).

2.3 Cost and performance indicators applied in the assessments

The refurbishment efficiency indicators and database for walls, windows, roof, etc. have been developed by VGTU experts. Based on the above database and tables of a multi-variant building design the possible refurbishment variants are then developed. When using the method of a multi-variant design as suggested by the author up to 100,000 alternative building refurbishment projects may be obtained. These project versions are checked for their capacity to meet the various requirements. Those that do not satisfy these requirements are excluded from any further consideration (see Appendix 2). The refurbishment efficiency indicators should be different for different types of buildings and different for different building parts.

The energy saving (U-value (W/m^2K), heating energy consumption (kWh/m^2)) and quality of life (particle pollution, electromagnetic pollution, illumination, volume flow, air velocity, air temperature, relative humidity, dew point temperature, vibration impulse amplitudes) indicators developed by VGTU experts are employed for facilities management stage (see Appendix 2). The energy saving and quality of life indicators can be the same for different types of buildings.

The assessed indicators are documented and reported in the internal VGTU form. The internal VGTU documentation and reporting of the assessed indicators can be used in later phases of the construction and real estate processes. The indicators are the starting point to show whether there are or will be problems with indicators at higher levels.

2.4 Relation to different enterprises and national benchmarking

Different CREDIT information model indicators (1.2.2. Operation, 1.1.5. Construction of building, 3.4. Thermal comfort, 3.5. Air quality and health, 3.7. Acoustic climate, 4.4. Thermal quality, 4.5. Impact on air quality, 4.6. Lighting quality, 4.7. Acoustic quality) have been used in the national case study. Refurbishment efficiency indicators are used in the design stage. The energy saving and quality of life indicators are used during operational stage (see Appendix 2). We did not use any information from other projects, benchmarking systems or from assessments of other projects. The developed indicators and obtained experience can be used in other projects.

2.5 Visions for future improvements

European citizens spend over 90 % of their time in closed space. In over 40 % of the closed spaces people complain of their health and comfort. Outside air pollution can cause respiratory and cardiovascular diseases, cancer, preterm birth and increased infant mortality, neurological and psychiatric disorders, worse immunity and hematologic characteristics. About 20 % of US citizens suffer from diseases caused by outside air pollution. Thus creation of healthy environment and improvement of the quality of life in closed spaces for Lithuanian residents is of a paramount importance. Ensuring quality of life in premises would improve productivity and reduce morbidity and health care expenditures. In case indoor environment becomes healthier and more comfortable for work, EU15 would save: 3-6 billion euros annually by reducing allergies and asthma (based on 8-25 % reduction of medical costs); 15-45 billion euros annually by reducing the symptoms of sick building syndrome (based on 20-50 % reduction and 2 % productivity improvement); 30-240 billion euros per year because productivity would increase by improving work conditions (if employee productivity increases by 0.5-5 %). Currently particle and electromagnetic pollution are very important for city inhabitants.

We have some plans for improvement the e-assessment methods and e-tools (this includes all step in an e-assessment process such as collecting and processing data and giving recommendations) for analysis of particle and electromagnetic pollution. We are under development Embedded Particle and Electromagnetic Pollution Recommender Systems. These systems are intelligent systems designed to perform a few dedicated functions with real-time computing constraints. It is embedded as part of complete Particle and Electromagnetic pollution measuring devices. For example, currently Embedded Particle Pollution Recommender System measure and analyse particle pollution and giving concrete recommendation how decrease particle pollution in premises.

3. Enterprises – assessments and indicators internally applied

VGTU expect that the companies will learn of the experiences from current case study and take them into account in coming projects. About 220 bachelor and master degree students are finishing their studies in our Department every year. These students are acquainted with construction and refurbishment efficiency, energy saving and quality of life indicators.

3.1 The actual enterprise, company and firm

In 1990 the Vilnius Civil Engineering Institute became Vilnius Technical University, which on August 22, 1996 was awarded the name of Gediminas, Great Duke of Lithuania. At present the University includes 8 faculties, Aviation Institute named after A.Gustaitis, International Studies Centre, Centre for Continuous Education, 10 research institutes and 19 laboratories. On Sept 1, 2005 over 14 849 students came to the University's classrooms, with 3 491 of them being first-year students. Teaching staff numbers 919, including 50 Research fellows. There are also 117 Doctors Habil and Professors, 508 Doctors or Associate Professors, 75 Lectors and 248 Assistants. The University provides 88 programmes for diploma engineers, undregraduate and graduate (Bachelor and Master) studies in the fields of Humanity Sciences, Physical Sciences, Social Sciences, Technological Sciences, Biomedical Sciences and Art Sciences.

The site of the renovated Laboratory Building of Vilnius Gediminas Technical University (VGTU) is suburban. The surrounding of VGTU are Vilnius university (VU), residential housings and forest. VGTU Laboratoric Building was built up in 1971. It includes several departments and lecture halls. Number of occupants – 1084, number of rooms – 219.

3.2 Assessment methods and tools applied in the enterprise

The assessments have been executed by VGTU local experts.

3.3 Costs and performance indicators applied in the enterprise

Energy and indoor climate indicators are included in the internally assessment of VGTU.

3.4 Relation to building cases and national benchmarking

Currently Lithuania did not have the benchmarking systems.

3.5 Visions and innovation for future improvements

It is the opinion of VGTU that the experiences concerning multivariant design, multiple criteria analysis and selection of most effective alternative of the projects should be spread to other clients and sectors within the construction and real estate sector. By using digital alternative versions analysis VGTU contribute to the digital construction and real estate process.

It is the opinion of VGTU that the CREDIT indicators give the client as well as the companies' possibility to learn more about the effectiveness and quality of the executed work. And use the results in new projects. The indicators can stimulate thinking about all the phases in the building process – from the idea and the first discussions to details in the project and further to work on the building site. Furthermore the results can be used in connection with education and post education at the level of the individual companies and in workshops and conferences for several companies.

4. National benchmarking – indicators, assessment and organisation

On the background of evaluation of energy efficiency, multivariant design and multiple criteria analysis of the renovation of VGTU Laboratory Building and quality of life analysis it has been possible for VGTU to develop recommendations for the efficiency increasing of the building refurbishment and improving quality of life which are disseminated to the stakeholders in construction and real estate during distance and lifelong learning, conferences, newspapers. The statistic and information are collected in accordance with different aspects on the building and quality of life. In this way it is also possible for stakeholders to see the results of the efficiency of renovation of VGTU Laboratory Building and quality of life. If necessary VGTU will also publish recommendations about efficiency increasing of renovation and rising of quality of life by using multivariant design and multiple criteria analysis methods and intelligent systems.

4.1 The actual benchmarking organization and its purpose

Currently Lithuania did not have a benchmarking system for construction and real estate sector.

4.2 Assessment applied in the benchmarking organization

Lithuania still did not have a national benchmarking system. Only some individual organisations carry out inspections.

4.3 Cost and performance indicators applied in benchmarking

Therefore, we can analyse only VGTU experience in carrying out inspections. The building inspections register for main parts (windows, walls, roof, doors, ventilation) of the building, which are essential for the energy saving and quality of life. A system of energy saving (U-value (W/m^2K), heating energy consumption (kWh/m^2)), quality of life (particle pollution, electromagnetic pollution, illumination, volume flow, air velocity, air temperature, relative humidity, dew point temperature, vibration impulse amplitudes) and other indicators (Appendix 2) have been analysed.

The energy efficiency, quality of life and other indicators (see Appendix 2) can be used in the planning or construction and refurbishment. And due to the dissemination of information they can be as part of the planning and execution of coming projects.

4.4 Relation to enterprises, building projects and real estate

The energy efficiency, quality of life and other indicators are used in eventually repair work and in the operation of the building. And due to the dissemination of information they can be as part of the planning and execution of coming projects.

The information concerning energy efficiency and quality of life is presenting for responsible persons in VGTU. The responsible persons in VGTU evaluate the energy efficiency and quality of life situation and take some practical solutions.

In addition to the mentioned activities VGTU researchers and professors takes initiative to considerable exchange of the results via bachelor and master degree courses, lifelong learning, distance learning and articles.

4.5 Visions and innovation for future improvements

In 2.5 Visions and innovation for future improvements VGTU's considerations concerning improvements are described.

5. Discussions and conclusions

The experiences from local inspections give VGTU some valuable lessons about good and bad practice. And the lessons gives at the same time the whole construction and real estate sector the possibility learn developed multiple criteria and quality of life analysis methods.

5.1 Buildings – lessons learned and recommendations

The developed multiple criteria and quality of life analysis methods give VGTU an effective instrument for multivariant design, multiple criteria analysis, selection best retrofit alternatives and monitoring the quality of life. By making evaluation of energy efficiency and quality of life after refurbishment of VGTU Laboratory Building it is possible to get information concerning the usefulness of methods, components and materials in practice which is very valuable not only for VGTU but for the whole construction and real estate sector in Lithuania.

It can be mentioned that the Lithuanian Parliament in 2007 issued a Law on Construction: Warranty Period of a Construction Period. Obligations of the Designer, Contractor of a Construction Works and Technical Supervisor of Construction of a Construction Works during a Warranty Period.

5.2 Enterprises - lessons learned and recommendations

It is the opinion of VGTU that the multiple indicators give the stakeholders possibility to learn more about the effectiveness of renovation and achieved quality of life. And use the results in new projects.

The multiple indicators can increase efficiency of the all building lifecycle process – brief, design, construction, maintenance, facilities management, demolition, utilization.

If necessary VGTU will also publish best practice related to developed multiple criteria and quality of life analysis methods. Some examples are particle pollution in the premises after renovation, allergens, electromagnetic pollution.

In case indoor environment becomes healthier and more comfortable for work, EU15 would save: 3-6 billion euros annually by reducing allergies and asthma (based on 8-25 % reduction of medical costs); 15-45 billion euros annually by reducing the symptoms of sick building syndrome (based on 20-50 % reduction and 2 % productivity improvement); 30-240 billion euros per year because productivity would increase by improving work conditions (if employee productivity increases by 0.5-5 %) [1].

5.3 National benchmarking - lessons learned and recommendations

On background of the multivariant design and multiple criteria analysis of the renovation of VGTU Laboratory Building and quality of life analysis it has been possible for VGTU to develop recommendations for the efficiency increasing of the building refurbishment and improving quality of life which are disseminated to the stakeholders in construction and real estate during distance and lifelong learning, conferences, newspapers.

In 2008 the Danish Parliament issued a law concerning private housing in accordance with which it is obligatory for a developer or contractor to sign an insurance concerning possible defects in new dwellings. The law is based on experiences from the Fund.

In 2.5 Visions and innovation for future improvements the Fund has described its experiences and considerations about improvements.

References

1. European Construction Technology Platform. (2005). Quality of Life – Towards a Sustainable Built Environment. 53 p.

Appendix 1: Warranty period of a construction works

Article 36. Warranty Period of a Construction Period. Obligations of the Designer, Contractor of a Construction Works and Technical Supervisor of Construction of a Construction Works during a Warranty Period

1. The warranty period of a construction works shall be fixed in contracts, contracts related to construction works design and technical supervision of construction of a construction works. Such period may not be less than five years (counting from the day of the acceptance of a construction works as fit for use); for hidden elements of a construction works (structures, pipelines, etc.) - ten years, and if defects which have been deliberately hidden are established - twenty years.

2. The designer, the contractor of a construction works and the technical supervisor of construction of a construction works shall be liable for collapse of a construction works or the defects established during a warranty period in accordance with the procedure established by the Civil Code.

3. The warranty period shall be suspended for such length of time during which the construction works cannot be used due to the established defects for which the contractor is liable.

4. The warranty period of construction products and equipment which are not related to the requirements of paragraph 1 of Article 4 of this Law (except those which are in hidden structures of a construction works) shall be set in documents issued by the supplier.

Appendix 2: Building's Refurbishment Knowledge and Devices Based Decision Support System

1. Introduction

The present Case study of a Renovation Project of VGTU Laboratory Building have suggested the idea of integrating knowledge-based, devices-based, environment friendly and decision support systems. In order to demonstrate the integration of the above systems in the real estate sector, a Building's Refurbishment Knowledge and Devices Based Decision Support System (BR-KD-DSS) have been developed. In order to check the correctness of the developed System, the whole of its solution process has been gone through manually. The results of manual and computer calculations matched. Besides, all separate working stages of the System as well as all subsystems have been coordinated with experts in this field - i.e. the essence of the calculations has been found to be in conformity with the expert's logical reasoning. Owing to suggestions from these experts, some useful changes have been introduced into the System. The check-up by the experts is bound with the fact that universal decision making methods are not always suitable for specific tasks and can lead to gross errors or to bad results. The results of the developed System were introduced to the present Case study of a Renovation Project of VGTU Laboratory Building. During the creation of BR-KD-DSS a particular input in the development of cooperative decision making methods in general was performed by the integrating cooperative decision making methods with multiple criteria analysis methods, proposed by author: a method of complex determination of the weights of the criteria taking into account their quantitative and qualitative characteristics; a method of multiple criteria complex proportional evaluation of the projects; a method of defining the utility and market value of a project. BR-KD-DSS consist of a database, database management system, model-base, model-base management system, devices, facilities management, market value analysis, premise's microclimate, pollution, human emotions analysis subsystems and a user interface.

2. VGTU Laboratory Building

The site of the Laboratory Building of Vilnius Gediminas Technical University (VGTU) is suburban. The surrounding of VGTU are Vilnius university (VU), residential housings and forest. VGTU Laboratoric Building was built up in 1971. It includes several departments and lecture halls. Number of occupants – 1084, number of rooms – 219.

The substructure of the building is made from frame pillar with columns of UK type. The walls of the building have the ferroconcrete frame and three-layer ferroconcrete panels (60/90/90). The thermal transmittance of walls U_w □ 1.07 W/m^2K. During thirty years of exploitation, both sun and rainfall have impacted on external sectors partitioned off. Somewhere, connection junctures of three-layer panels are already partly crumbled. Such sealing junctures are easily blowable and pervious to moisture. Juncture in damaged places of the external sectors partitioned off is sealed with warm sealing material – hernit and stopped up with a sealant.

Fig. 1. Laboratory Building of Vilnius Gediminas Technical University (VGTU) before renovation

The biggest part of the external sectors partitioned off in the laboratory facades is occupied by glass area. All window glass is placed in wooden or aluminium profile frameworks. The windows of the laboratory building are very old. Closing windows and lack of tightness are the biggest inconveniences. Current construction of the windows does not correspond to the modern window requirements and does not ensure proper inside comfort conditions. The thermal transmittance of windows U_{wi} □ 2.5 W/m^2K.

Lateral entrance doors in the laboratory building are old, unsealed and very insecure as well. The thermal transmittance of doors U_d □ 2.3 W/m^2K.

All roofs of the building are flat, and the covering is made from the roll.

Heating system of the laboratory building VGTU has been working for already thirty years. The heating system is connected to the central heating system according to the independent scheme of connection. Since the laboratory building VGTU is pretty long, facade regulation of the heating system was carried out in the new thermal unit. Both filiations of heating system were connected to the Central heating system with the help of tabular heating elements, circulating pumps of heating system, and automated regulation of heat quantity as well, which depends on outside temperature. Besides, the regulation of heat quantity may work within diminished temperature work regime in respect of twenty-four hours and days of week. Heating system works according to the diminished temperature schedule from 4 p.m. until 4-5 a.m. as well as on Saturdays and Sundays. With the aim to heat up the laboratory building, the single-pipe heating system of lower distribution is designed and installed. Heating devices are sectional radiators M-140 AO, and convector heaters in lobbies. Mostly heating devices are covered. If there is no basement and the ground floor is on the ground, then trunk pipelines are installed in the pathless underground canals. Additionally, in socle floor premises these pipelines are installed openly near the floor. Therefore, the old and covered heating devices, the old and a little permeable pipelines as well as hardly controlled reinforcement cannot fulfil heating functions of the building even having renovated thermal unit and facade regulation. During heating season, when the windows are not tight, an inside temperature is approximately 14ºC - 16ºC.

In the thermal unit façade regulation of building heating systems is installed. Closing valve, filter, indicator of temperature of initial t_1 temperature and recursive temperature t_2, two thermal transmitters, pumps, expansion vessels and façade indicators are equipped in the thermal unit. Hot water in the laboratory building is only in several points of hot water as is prepared with the help of electric volumetric thermal transmitters.

Ventilation system. In the Technical project of VGTU, mechanical air supply/removal systems were foreseen to install in the Laboratory building VGTU. Air paths were installed in particular facilities (between walls) and in the suspended ceiling as well. At the moment, the old mechanical air supply/removal systems are not in use in the Laboratory building because they need a lot of electric power. Besides, the old systems are too noisy for the building having a particular purpose.

Illumination and electrical engineering. When visiting and talking to Computation centre specialists, there were some complains about electrical engineering for computers and other electrical needs of the building are connected from the one point. Especially, it is relevant in cold period of the year when some additional heating devices are being connected and protectors cut out the electric power. In addition, the computers are also disconnected. In all the departments there was a wish expressed to install new lines of electric power supply designed only for computers. The installation for computers should be connected to earth.

Additionally, illumination engineering is also out-of-date and does not meet the modern requirements. There are old luminescential illuminators without covering in some offices or auditoriums. The level of facilities illumination is insufficient as well.

3. Building's Refurbishment Knowledge and Devices Based Decision Support System

Building's Refurbishment Knowledge and Devices Based Decision Support System (BR-KD-DSS) consist of a database, database management system, model-base, model-base management system, devices, facilities management, market value analysis, premise's microclimate, pollution, human emotions analysis subsystems and a user interface.

The BR-KD-DSS allows users to: present information of the general physical and functional state of the building; present information of the physical state of the building's envelope; rationalize the energy consumption of the building; propose the required measures to increase the quality of air and indoor environment and analyze the refurbishment and facilities management scenarios by taking into account the system of criteria, etc.

3.1. Building's Refurbishment Database

Building refurbishment involves a number of interested parties (i.e. clients, users, designers, contractors, suppliers, facilities management organizations, local authorities, government and its institutions, etc.) who pursue various goals and have different potentialities, educational levels and experiences. This leads to various approaches of the above parties to decision making in this field. In order to do a full analysis of the available alternatives and to obtain an efficient compromise solution, it is often necessary to define the differences on the basis of economic, ecological, indoor environmental quality (humidity, noise, thermal comfort, air quality (and ventilation), lighting, safety and security, apartment utilities), legal, social, technical, technological and other type of information. This information should be provided in a user-oriented way.

Economic information on building refurbishment includes the building and plot costs, laboratorytenance costs, insurance, taxes and interest rates (in case of crediting), etc. This information may be described in minor detail.

The crediting of refurbishing may be provided by various sources. Therefore, some additional information on alternative crediting sources and terms might be quite helpful for decision- makers.

Technical building characteristics include the total and usable building area, the number and dimensions of rooms, technical characteristics of utilities and the like.

Table 1. The initial data for multiple criteria analysis of thermal renovation of walls

Criteria under evaluation	Measu-ring units of criteria	*	Weights of criteria	Ltd "Skala"	Ltd "Fasadų renovacija"	Ltd "Baira-miksas"	Ltd "Stat-reksas“	Ltd "Kreisel Vilnius"	Ltd "Impa-ratas"	Ltd "Atri-butas"	Ltd "Alke-sta"	Ltd "Nausasis Fasadas" (New Facade)
Price	Lt	-	0.6	390425	400125	394790	395275	458900	354050	383150	392850	407400
Adhesive (glued) joint strenght (concrete/thermal insulating board)	N/mm^2	+	0.0148	0.12	0.1	0.5	0.1	0.5	0.1	0.1	0.1	0.12
Adhesive (glued) joint strenght (concrete/concrete)	N/mm^2	+	0.0052	1.3	1	1.2	1	1	1.6	1.2	1.3	1
Thermal conductivity of thermal insulating board	W/mK	-	0.084	0.038	0.041	0.039	0.041	0.039	0.038	0.039	0.038	0.041
Compressive strength of thermal insulating board	kPa	+	0.013	40	50	40	50	40	50	40	40	50
Tensile stength of thermal insulating board perpendicular to the surface	kPa	+	0.016	15	80	15	80	15	15	15	80	80
Density of thermal insulating board	kg/m^3	-	0.007	150	80	80	80	140	140	150	90	80
Compressive strength of reinforcing mix	N/mm^2	+	0.018	10.2	11.7	8.7	10.2	11.7	10.2	8	10.2	8.7
Bending strength of reinforcing mix to thermal insulating board	N/mm^2	+	0.032	1.2	1	1.2	1.2	1.2	1.2	0.7	1.2	0.5
Fabric reinforcement weight	gr/m^2	+	0.008	170	165	165	160	165	165	170	165	165
Tensile strength of fabric reinforcement smt1	N	+	0.016	2075	2100	2000	2000	2075	2000	2100	2000	2075
Tensile strength of fabric reinforcement smt2	N	+	0.016	2180	2250	2100	2100	2180	2100	2250	2100	2180
Compressive stength of decoration plaster	N/mm^2	+	0.01	6	4	2	6	2	6	5.7	6	2
Water absorption coefficient of decoration plaster	$kg/m^2h^{0,5}$	-	0.012	0.2	0.3	0.35	0.14	0.35	0.3	0.35	0.3	0.35
Bending strength of decoration plaster to concrete	N/mm^2	+	0.023	1.7	0.8	1.7	1.7	0.8	1.7	0.7	1.7	0.8
Reduction of decoration plaster compression strength after 25 freezing cycles	%	-	0.015	20	19	24	24	15	24	19	24	15
Extraction force of a pin fastening thermal insulating board to solid materials	kN	+	0.03	0.25	0.25	0.25	0.27	0.25	0.25	0.5	0.25	0.25
Guarantee period	years	+	0.031	7	5	6	7	5	7	5	5	7
Service life (lonevity)	years	+	0.039	30	35	40	30	40	30	35	30	40
Completion date	days	-	0.01	65	60	60	60	60	60	70	70	60

The presentation of information needed for decision-making in the BR-KD-DSS may be in a conceptual form (digital/numerical, textual, graphical, diagrams, graphs and drawing, etc), photographic, sound, visual (video)) and quantitative forms. Therefore, the presentation of quantitative information involves criteria systems and subsystems, units of measurement, values and initial weight that fully define the provided variants. Conceptual information means a conceptual description of the alternative solutions, the criteria and ways of determining their values and the weight, etc.

In this way, the BR-KD-DSS enables the decision-maker to receive various conceptual and quantitative information on building refurbishment from a database and a model-base allowing him/her to analyze the above factors and to make an efficient solution.

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

- Initial data tables. These contain general facts about the building considered and the information of its deterioration and obsolescence. The reasons for refurbishing and their significance as well as the money to be spent on it are also included.
- Tables assessing refurbishment solutions (walls (see Table 1), windows (see Table 2), roof, floors, volumetric planning and engineering services, etc.). These contain quantitative and conceptual information about alternative building refurbishment solutions relating to a building's enclosures, utilities and space planning, etc.
- Tables of multi-variant design. These provide quantitative and conceptual information on the interconnection of the elements to be renovated, their compatibility and the possible combinations as well as data on the complex multi-variant design of a building refurbishment.

Table 2. The initial data for multiple criteria analysis of thermal renovation of windows

Criteria under evaluation	Measuring units of criteria	*	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Price	Lt	-	0.6	247525	192079	279267	312686	302970	269307	304950	366337	258360	235962	202156.54	285636.83	322570
Mechanical strength and stiffness	-	+	0.0275	1	1	1	1	1	1	1	1	1	1	1	1	1
Reliability	Cycles	+	0.0291	20000	20000	20000	20000	20000	20000	20000	20000	1000	10000	10000	1000	1000
Thermal transmission coefficient of profile	W/m^2K	-	0.0284	1.7	1.7	1.7	1.4	1.4	1.4	1.7	1.4	1.63	1.4	1.2	1.4	1.4
Thermal transmission coefficient of double glazing unit	W/m^2K	-	0.0322	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.14	1.1	1.1	1.2	1.1
Emission ability of low emissive glass coating e	-	-	0.023	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.1	0.05
Parameter of air sound isolation Rw	dB	+	0.0259	31	31	36	31	31	36	40	40	32	34	34	33	33
Air leakage, when pressure difference Dp = 50 Pa	(m^3/m^2h)	-	0.0246	0.6	0.06	0.6	0.6	0.3	0.3	0.6	0.3	0.31	0.18	0.18	0.15	0.3
Waterproofness	Pa	+	0.0302	450	450	450	450	250	250	450	250	100	600	600	300	250
Guarantee period	years	+	0.0302	5	5	5	5	5	5	5	5	5	5	10	5	5
Durability	years	+	0.0309	50	50	50	50	50	50	50	50	30	50	35	30	40
Light transmission of double glazing unit	%	+	0.022	0.75	0.78	0.74	0.75	0.75	0.74	0.67	0.67	78	81	81	78	79
Pay-back period	years	-	0.0262	0	0	0	0	0	0	0	0	25.9	30	13.2	40	45
Duration of works	days	-	0.0225	0	0	0	0	0	0	0	0	60	60	60	50	60
Quantity of windows with two opening positions (horizontal and vertical) (in percent of the area of all windows)	%	+	0.0215	100	50	100	100	100	50	100	100	27.43	37	78.5	100	100
Quantity of windows with closing infiltration air vent or the third opening position (in percent of the area of all windows)	%	+	0.0258	100	100	100	100	100	100	100	100	27.43	37	78.5	100	100

The collection, processing and presentation of information for database in an acceptable form are a complicated and time-consuming process. The information collected in a database should be reliable, fully describing a building refurbishment and enable the BR-KD-DSS to perform an efficient multi-variant refurbishment design and multiple criteria analysis.

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

Tables of initial data contain the following information:

- General facts about the building to be analyzed;
- Results of diagnosis and questionnaires (data on the deterioration and obsolescence of a building, etc.);
- Top priority and significance of the building refurbishment objectives;
- The amount of money intended for refurbishment.

The user seeking for an efficient refurbishment of a building should provide in the tables of the initial data the exact information about a building's deterioration and obsolescence, refurbishing aims and significance as well as the client's financial situation. It should be noted that various clients making refurbishment design variants and a multiple criteria analysis of the same building often get diverse results. This may be due to the diversity of the overall aims and financial positions of the clients. Therefore, the initial data provided by various clients for calculating the refurbishment project differ and consequently lead to various final results.

The tables of refurbishing variant assessments contain the evaluation data on building refurbishment and referring to:

- Specific elements of a building including:

- The fixing of balconies, canopies and cornices;
- The sealing of a building's joints and external walls;
- Thermal renovation of walls, windows, roofs, etc.;

- Engineering services (water supply, sewerage, heating system, etc.).

- Structural-spatial changes.

The tables of refurbishing variant assessments contain the variants available and their quantitative and conceptual description. The process of drawing up the tables of refurbishing variant assessments consists of the following steps:

- Collection and presentation of general information about the variants under consideration,
- Establishment and conceptual description of the systems and subsystems according to the criteria,
- Choosing the units of measurement,
- Estimation of the values of the criteria with a description of the calculation process and its presentation,

Determination of the initial weight of the criteria with a description of the calculation process and its presentation

The information used in compiling the tables of refurbishing variant assessments is based on the use of diagnosis, questionnaires, building cost indices by referring to the costs incurred by contractors (labor, materials, plant and overheads (excluding profits)); tender price indices which reflect the cost to the client (bills of quantities from successful tenders, unit prices as published in builders' price books or trade journals (includes overheads and profits); various statistical methods, analyzed projects and recommendations, etc.

The owner and the occupants of a building being refurbished have their specific needs and financial situation. Therefore, every time when using the BR-KD-DSS they may make corrections of the database according to their aims and their financial situation. For example, a certain client considers the sound insulation of the external walls to be more important than their appearance while another client is quite of the opposite opinion. The client striving to express his/her attitude towards these issues numerically may ascribe various significance values to them that eventually will affect the general estimation of a project. Though this assessment may seem biased and even quite subjective, the solution finally made may exactly meet the client's requirements, aims and affordability.

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

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

In order to design and realize an effective building refurbishment project the alternatives available should be analyzed. A computer-aided multi-variant design requires the availability of the tables containing the data on the interconnection of the elements to be renovated and the solutions made. It also requires their compatibility, possible combination and the multi-variant design.

Since the objectives and financial situations of the BR-KD-DSS users often vary the initial design data then consequently the results obtained will also be different. Therefore, the objectives and the client's financial situation are expressed quantitatively and provided as the initial data for calculations. These data should be related to the other information in the tables. Based on the above tables of a multi-variant building design the possible refurbishment variants are then developed. When using the method of a multi-variant design as suggested by the authors [5, 6, 7, 8] up to 100,000 alternative building refurbishment projects may be obtained. These project versions are checked for their capacity to meet the various requirements. Those that do not satisfy these requirements are excluded from any further consideration.

In designing a number of variants of building refurbishment the problem of weight compatibility of the criteria also arises. In this case, when a complex evaluation of the alternatives is carried out, the value of the criteria's weight is dependent on the overall criteria being assessed as well as on their values and the initial weight.

3.2. Building's Refurbishment Model-base

The efficiency of a building refurbishment variant is often determined by taking into many factors. These factors include an account of the economic, aesthetic, technical, comfort, legal, social and other factors. The model-base of a decision support system should include models that enable a decision-maker to do a comprehensive analysis of the available variants and to make a proper choice.

The more alternative versions that are investigated before making a final decision, the greater the possibility to achieve a more rational end result. Basing oneself on the collected information and the BR-KD-DSS it is possible to perform a multiple criteria analysis of the refurbishment project's components (walls, windows, roof, floors, volumetric planning and engineering services, etc.) And select the most efficient versions. After this, the received compatible and rational components of a refurbishment are joined into the projects. Having performed a multiple criteria analysis of the projects in this way, one can select the most efficient projects. Strengths and weaknesses of the investigated projects are also given in an analysis. Facts as to why and to what degree one version is better than another are also established. All this is done by basing oneself on conceptual and quantitative information that was collected.

Module base provides support to the user so that he/she can develop different alternatives that are based on combinations of the user's requirements. The developed measures are checked for consistency of measure combinations as well as for interference with deterioration, obsolescence and other related actions. Each alternative shows different levels of improvements to the building's quality and all have variations in the projected cost. A module base allows the BR-KD-DSS's user to select the most suitable refurbishment alternatives by comparing the measures that promote the greatest energy savings and increase a building's quality within the budget constraints of the building's inhabitants.

The following models of a model-base aim at performing the functions of:

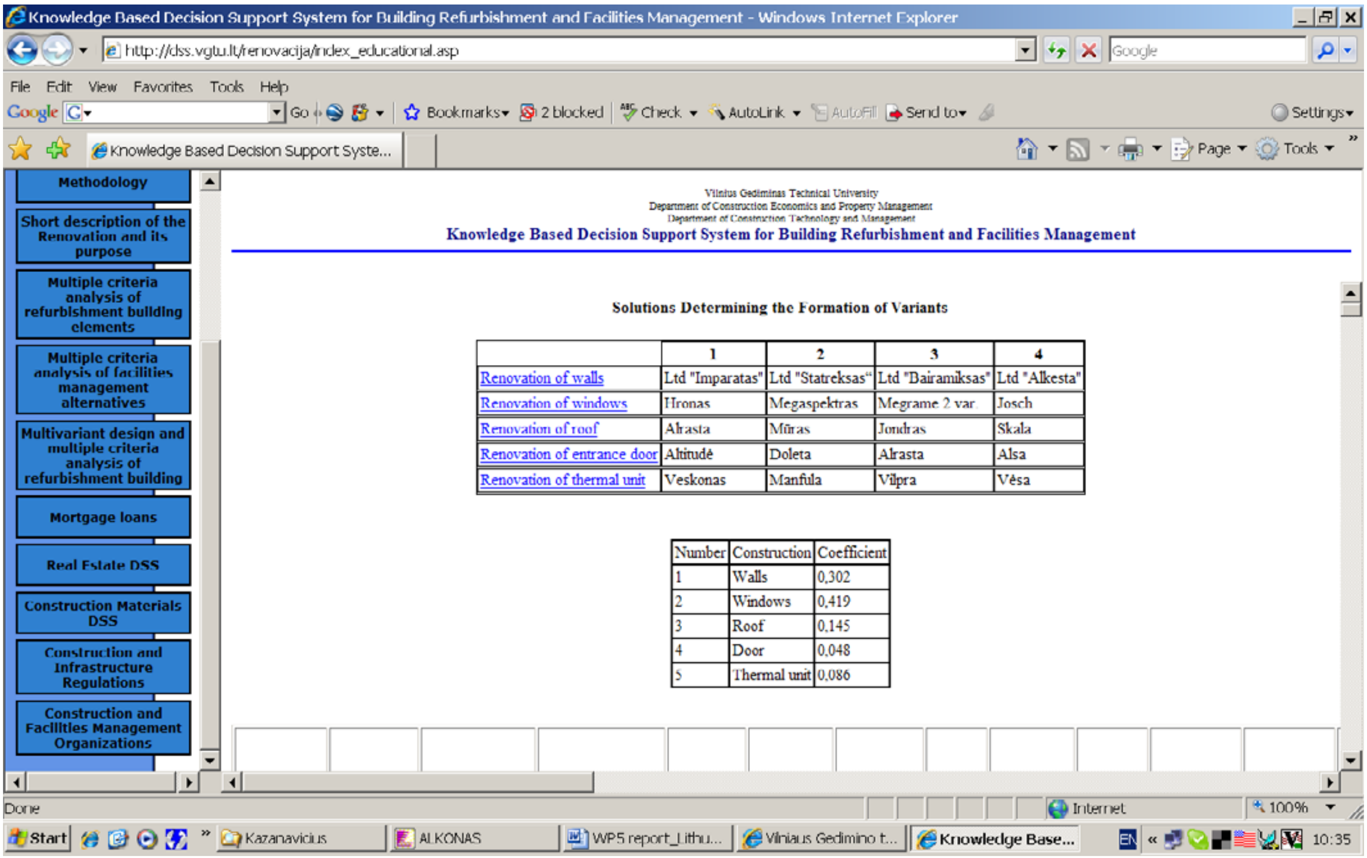
- A model for developing the alternative variants of a building's enclosures,
- A model for determining the initial weight of the criteria (with the use of expert methods),
- A model for the establishment of the criteria weight,
- A model for the multi-variant design of a building refurbishment,
- A model for multiple criteria analysis and for setting the priorities,
- A model for the determination of a project's utility degree and market value,
- A model for providing recommendations.

Table 3. Multiple criteria analysis and selection of the most efficient renovation alternatives of the walls

Criteria under evaluation	Measuring units of criteria	*	Weights of criteria	Ltd "Skala"	Ltd "Fasadų renovacija"	Ltd "Bairamiksas"	Ltd "Statreksas“	Ltd "Kreisel Vilnius"	Ltd "Imparatas"	Ltd "Atributas"	Ltd "Alkesta"	Ltd "Nausasis Fasadas" (New Facade)
Price	Lt	-	0,6000	0,0655	0,0671	0,0662	0,0663	0,0770	0,0594	0,0643	0,0659	0,0683
Adhesive (glued) joint strenght (concrete/thermal insulating board)	N/mm^2	+	0,0148	0,0010	0,0009	0,0043	0,0009	0,0043	0,0009	0,0009	0,0009	0,0010
Adhesive (glued) joint strenght (concrete/concrete)	N/mm^2	+	0,0052	0,0006	0,0005	0,0006	0,0005	0,0005	0,0008	0,0006	0,0006	0,0005
Thermal conductivity of thermal insulating board	W/m K	-	0,0840	0,0090	0,0097	0,0093	0,0097	0,0093	0,0090	0,0093	0,0090	0,0097
Compressive strength of thermal insulating board	kPa	+	0,0130	0,0013	0,0016	0,0013	0,0016	0,0013	0,0016	0,0013	0,0013	0,0016
Tensile stength of thermal insulating board perpendicular to the surface	kPa	+	0,0160	0,0006	0,0032	0,0006	0,0032	0,0006	0,0006	0,0006	0,0032	0,0032
Density of thermal insulating board	kg/m^3	-	0,0070	0,0011	0,0006	0,0006	0,0006	0,0010	0,0010	0,0011	0,0006	0,0006
Compressive strength of reinforcing mix	N/mm^2	+	0,0180	0,0020	0,0024	0,0017	0,0020	0,0024	0,0020	0,0016	0,0020	0,0017
Bending strength of reinforcing mix to thermal insulating board	N/mm^2	+	0,0320	0,0041	0,0034	0,0041	0,0041	0,0041	0,0041	0,0024	0,0041	0,0017
Fabric reinforcement weight	gr/m^2	+	0,0080	0,0009	0,0009	0,0009	0,0009	0,0009	0,0009	0,0009	0,0009	0,0009
Tensile strength of fabric reinforcement smt1	N	+	0,0160	0,0018	0,0018	0,0017	0,0017	0,0018	0,0017	0,0018	0,0017	0,0018
Tensile strength of fabric reinforcement smt2	N	+	0,0160	0,0018	0,0019	0,0017	0,0017	0,0018	0,0017	0,0019	0,0017	0,0018
Compressive stength of decoration plaster	N/mm^2	+	0,0100	0,0015	0,0010	0,0005	0,0015	0,0005	0,0015	0,0014	0,0015	0,0005
Water absorption coefficient of decoration plaster	$kg/m^2 h^{0,5}$	-	0,0120	0,0009	0,0014	0,0016	0,0006	0,0016	0,0014	0,0016	0,0014	0,0016
Bending strength of decoration plaster to concrete	N/mm^2	+	0,0230	0,0034	0,0016	0,0034	0,0034	0,0016	0,0034	0,0014	0,0034	0,0016
Reduction of decoration plaster compression strength after 25 freezing cycles	%	-	0,0150	0,0016	0,0015	0,0020	0,0020	0,0012	0,0020	0,0015	0,0020	0,0012
Extraction force of a pin fastening thermal insulating board to solid materials	kN	+	0,0300	0,0030	0,0030	0,0030	0,0032	0,0030	0,0030	0,0060	0,0030	0,0030
Guarantee period	years	+	0,0310	0,0040	0,0029	0,0034	0,0040	0,0029	0,0040	0,0029	0,0029	0,0040
Service life (lonevity)	years	+	0,0390	0,0038	0,0044	0,0050	0,0038	0,0050	0,0038	0,0044	0,0038	0,0050
Completion date	days	-	0,0100	0,0012	0,0011	0,0011	0,0011	0,0011	0,0011	0,0012	0,0012	0,0011
Total sum of maximizing normalized balanced rates S_{+j}				0.0298	0.0295	0.0322	0.0325	0.0307	0.03	0.0281	0.031	0.0283
Total sum of minimizing normalized balanced rates S_{-j}				0.0793	0.0814	0.0808	0.0803	0.0912	0.0739	0.079	0.0801	0.0825
Object's significance Q_j				0.1122	0.1098	0.1131	0.1139	0.1024	0.1184	0.1108	0.1126	0.1075
Object's utility degree N_j				95%	93%	96%	96%	86%	100%	94%	95%	91%
Object's priority				5	7	3	2	9	1	6	4	8
Supply price				390.425,00	400.125,00	394.790,00	395.275,00	458.900,00	354.050,00	383.150,00	392.850,00	407.400,00
Market price				390.425,00	391.172,82	394.790,00	395.275,00	397.904,64	354.050,00	383.150,00	392.850,00	381.951,15

Table 4. Multiple criteria analysis and selection of the most efficient renovation alternatives of the windows

Measuring units of criteria	*	Weights of criteria	1	2	3	4	5	6	7	8	9	10	11	12	13
Price	Lt	-	0,600	0,0415	0,0322	0,0468	0,0524	0,0508	0,0451	0,0511	0,0614	0,0433	0,0395	0,0339	0,0479
Mechanical strength and stiffness	-	+	0,027	0,0021	0,0021	0,0021	0,0021	0,0021	0,0021	0,0021	0,0021	0,0021	0,0021	0,0021	0,0021
Reliability	Cycles	+	0,029	0,0032	0,0032	0,0032	0,0032	0,0032	0,0032	0,0032	0,0032	0,0002	0,0016	0,0016	0,0002
Thermal transmission coefficient of profile	W/m^2K	-	0,028	0,0025	0,0025	0,0025	0,0020	0,0020	0,0020	0,0025	0,0020	0,0024	0,0020	0,0018	0,0020
Thermal transmission coefficient of double glazing unit	W/m^2K	-	0,032	0,0024	0,0024	0,0024	0,0024	0,0024	0,0024	0,0026	0,0026	0,0025	0,0024	0,0024	0,0026
Emission ability of low emissive glass coating e	-	-	0,020	0,0015	0,0015	0,0015	0,0015	0,0015	0,0015	0,0015	0,0015	0,0019	0,0019	0,0019	0,0037
Parameter of air sound isolation Rw	dB	+	0,025	0,0018	0,0018	0,0021	0,0018	0,0018	0,0021	0,0023	0,0023	0,0019	0,0020	0,0020	0,0019
Air leakage, when pressure difference Dp = 50 Pa	(m^3/m^2h)	-	0,024	0,0033	0,0003	0,0033	0,0033	0,0016	0,0016	0,0033	0,0016	0,0017	0,0010	0,0010	0,0008
Waterproofness	Pa	+	0,030	0,0028	0,0028	0,0028	0,0028	0,0016	0,0016	0,0028	0,0016	0,0006	0,0037	0,0037	0,0019
Guarantee period	years	+	0,030	0,0022	0,0022	0,0022	0,0022	0,0022	0,0022	0,0022	0,0022	0,0022	0,0022	0,0043	0,0022
Durability	years	+	0,030	0,0026	0,0026	0,0026	0,0026	0,0026	0,0026	0,0026	0,0026	0,0016	0,0026	0,0018	0,0016
Light transmission of double glazing unit	%	+	0,022	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0043	0,0044	0,0044	0,0043
Pay-back period	years	-	0,026	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0044	0,0051	0,0022	0,0068
Duration of works	days	-	0,022	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0047	0,0047	0,0047	0,0039
Quantity of windows with two opening positions (horizontal and vertical) (in percent of the area of all windows)	%	+	0,021	0,0021	0,0010	0,0021	0,0021	0,0021	0,0010	0,0021	0,0021	0,0006	0,0008	0,0016	0,0021
Quantity of windows with closing infiltration air vent or the third opening position (in percent of the area of all windows)	%	+	0,02	0,0023	0,0023	0,0023	0,0023	0,0023	0,0023	0,0023	0,0023	0,0006	0,0008	0,0018	0,0023
Total sum of maximizing normalized balanced rates S_{+j}				0.0191	0.018	0.0194	0.0191	0.0179	0.0171	0.0196	0.0184	0.0141	0.0202	0.0233	0.0186
Total sum of minimizing normalized balanced rates S_{-j}				0.0512	0.0389	0.0565	0.0616	0.0583	0.0526	0.061	0.0691	0.0609	0.0566	0.0479	0.0677
Object's significance Q_j				0.0835	0.1028	0.0778	0.0727	0.0745	0.0798	0.0737	0.0661	0.0683	0.0785	0.0922	0.0673
Object's utility degree N_j				81%	100%	76%	71%	72%	78%	72%	64%	66%	76%	90%	65%
Object's priority				3	1	6	9	7	4	8	12	10	5	2	11
Supply price				247.525,00	192.079,00	279.267,00	312.686,00	302.970,00	269.307,00	304.950,00	366.337,00	258.360,00	235.962,00	202.156,54	285.636,83
Market price				247.525,0	192.079,00	279.267,00	285.412,19	287.305,72	269.307,00	286.254,51	284.130,93	206.381,70	235.962,00	202.156,54	217.392,15



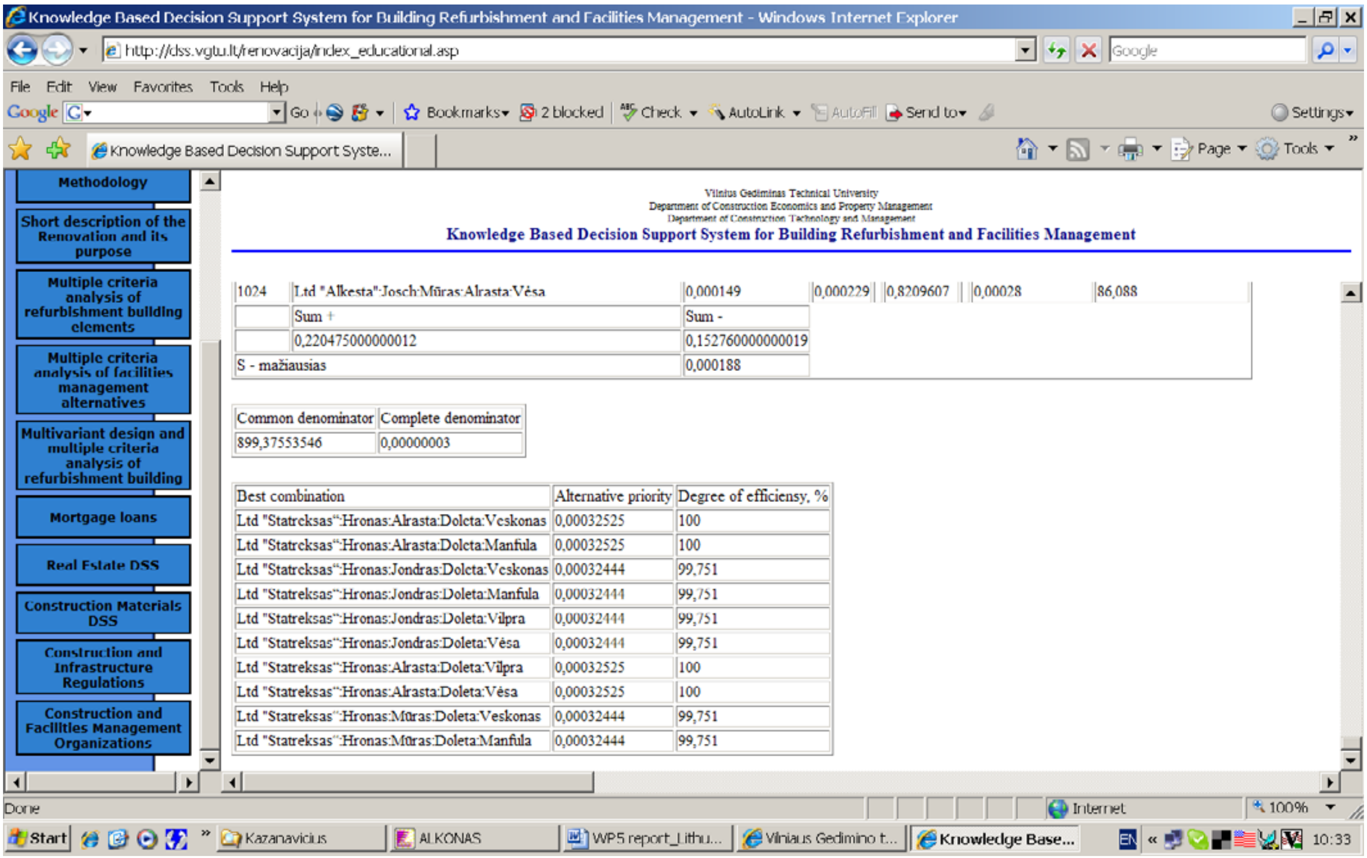


Table 5. Selection process of the most efficient alternatives of the VGTU Laboratory Building

Based on the above models, the BR-KD-DSS can make up to 100,000 building refurbishment alternative versions, perform their multiple criteria analysis, determine the utility degree and select the most beneficial variant without human interference.

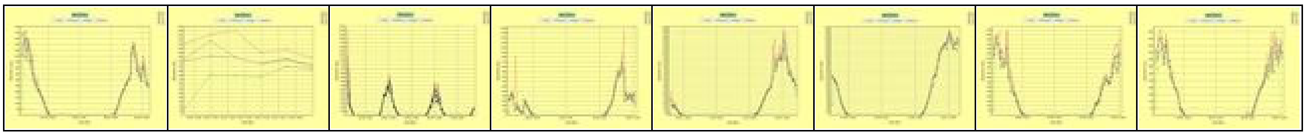
The BR-KD-DSS presents information about the building's diagnosis and questionnaires as well as different scenarios for the building's refurbishment. The report contains information about the estimation of potential energy savings and improvement of quality of building: thermal insulation of building envelope (walls, roof, windows); the cost of refurbishment work; comparison with the corresponding qualitative indices of an typical building built in the same period; potential impact of refurbishment to increase the quality of building to the level of present standard. This is useful software for the selection best possible scenarios.

The selected most beneficial variant have been used for renovation of the Laboratory Building of Vilnius Gediminas Technical University (see Fig.2).

Fig. 2. Laboratory Building of Vilnius Gediminas Technical University (VGTU) after renovation

Devices in the Devices Subsystem measure internal microclimate parameters (illumination, volume flow, air velocity, air temperature, relative humidity, dew point temperature, vibration impulse amplitudes (see Fig. 3)). The data is passed on to the Decision Support and the Knowledge subsystems. Let us analyze the internal volume flow and relative humidity as an example. Insufficient speed of the internal volume flow determines the lack of oxygen. As a result, internal hygiene conditions are worse, flowers wither and people feel unwell and their productivity decreases. Dry air in premises causes nasal mucous to dry and creates discomfort, thus productivity and good moods decrease. The discomfort may be removed by pipetting oil into the nose. Quite a few people encounter this problem. Other microclimate parameters may be described in a similar way.

Illumination



The vertical axis of the diagram shows Illumination in the premises (lux). The horizontal axis shows time interval of the research. Maximum values are red, minimum values are green and average values are blue.

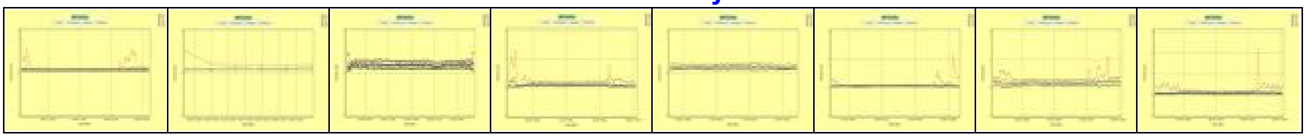
Volume Flow

The vertical axis of the diagram shows volume flow in the premises (m^3/h). The horizontal axis shows time interval of the research. Maximum values are red, minimum values are green and average values are blue.

Relative Humidity

The vertical axis of the diagram shows relative humidity in the premises (%). The horizontal axis shows time interval of the research. Maximum values are red, minimum values are green and average values are blue.

Air Velocity

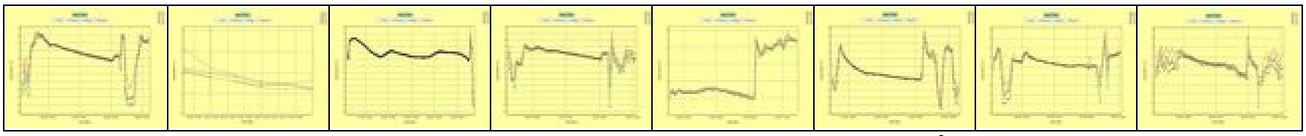


The vertical axis of the diagram shows air velocity in the premises (m/s). The horizontal axis shows time interval of the research. Maximum values are red, minimum values are green and average values are blue.

Air Temperature

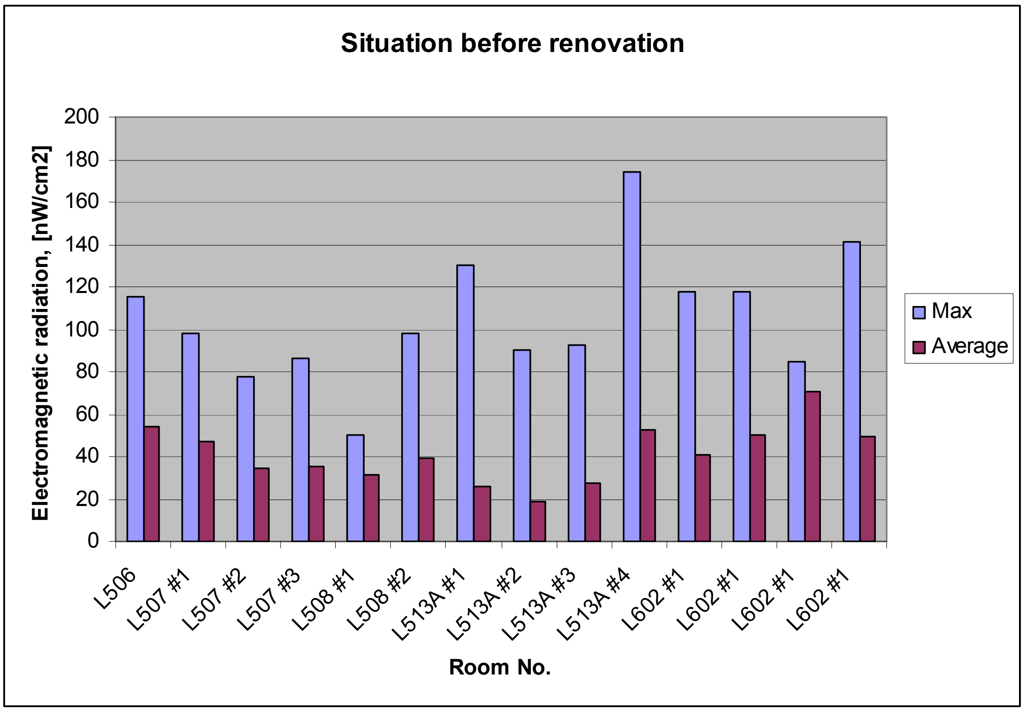
The vertical axis of the diagram shows air temperature in the premises (^{0}C). The horizontal axis shows time interval of the research. Maximum values are red, minimum values are green and average values are blue.

Dew Point



The vertical axis of the diagram shows dew point temperature in the premises (^{0}C). The horizontal axis shows time interval of the research. Maximum values are red, minimum values are green and average values are blue.

Fig. 3. Internal microclimate parameters (illumination, volume flow, air velocity, air temperature, relative humidity, dew point temperature, vibration impulse amplitudes) of the laboratory VGTU building



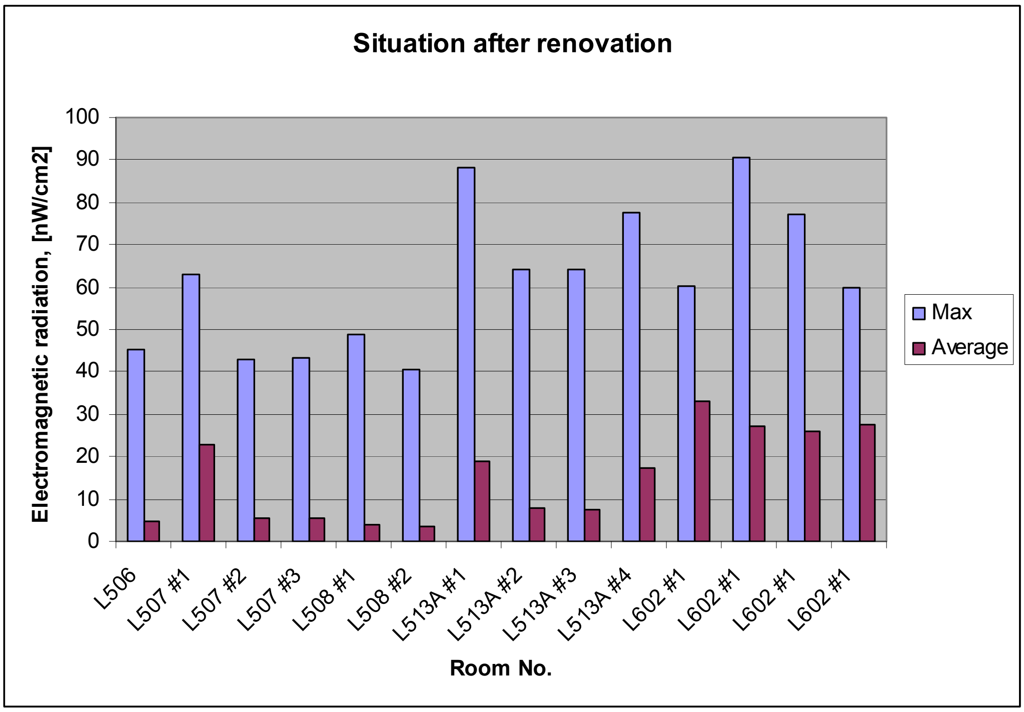


Fig. 4. Electromagnetic pollution before and after renovation

Fig. 5. Device for electromagnetic field measurement

Fig. 6. Airborn particle counting devices

Renovation outcomes of the laboratory VGTU building are presented in Table 6. Heating energy consumption [kWh/m²a] for the laboratory building of VGTU according to the conclusions of energy audit are presented in Table 7.

Table 6. Renovation outcomes of the laboratory VGTU building

Structural unit	U-value [W/m²K]	
	before renovation	after renovation
windows	2,5	1,16
walls	1,07	0,26
roof	0,8	0,3
doors	2,3	1,5

Table 7. Heating energy consumption [kWh/m²a] for the laboratory building of VGTU according to the conclusions of energy audit

Heating energy consumption [kWh/m²]				
Before retrofitting (2002)	After retrofitting			
	(2005/06)	(2006/07)	(2007/08)	(2008/09)
178	157	88	73,94	57,76

4. Conclusion

The presented BR-KD-DSS for a building's refurbishment enables one to form up to 100,000 alternative versions. This system allows one to determine the strongest and weakest points of each building's refurbishment project and its constituent parts. Calculations are made to find out by what degree one version is better than another and the reasons why this is so are disclosed. Landmarks are set for increasing the efficiency of a project's versions. All this is done argumentatively by basing oneself on the criteria under investigation, as well as on their values and weights. Also BR-KD-DSS can analyse facilities management alternatives, calculate market value of renovation projects, analyse premise's microclimate, pollution and human emotions.

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Construction and Real Estate -
Developing Indicators for Transparency

This report describes the results of a case study of renovation of VGTU Laboratory Building. The study was undertaken as part of the Nordic and Baltic project CREDIT: Construction and Real Estate – Developing Indicators for Transparency.

The analysis is aiming at three levels: the project or building, the firm and the national benchmarking system.

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