

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

Lina UŽŠILAITYĖ

MODEL OF ENERGETIC MODERNISATION OF PUBLIC BUILDINGS

SUMMARY OF DOCTORAL DISSERTATION

TECHNOLOGICAL SCIENCES,
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VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

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DAKTARO DISERTACIJOS SANTRAUKA

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Introduction

Scientific problem. Modernisation is an important component of building operation and maintenance system, during which the building physical and moral value is restored, energy efficiency and thermal comfort is improved, and environmental impact is reduced. However, at the moment a need for buildings modernisation is estimated in accordance with the economic and physical deterioration criteria. Such an approach is not in line with long-term building value maintenance strategy and is insufficient to ensure compliance with one of the essential requirements for buildings – building energy economy and heat retention.

The thesis investigated what criteria may be applicable for objective assessment of public building modernisation and what impact will be made by modernisation of building envelopes and systems maintaining microclimate and air quality parameters on building life cycle, with regard to the trends of tightening requirements for building energy performance and technological progress.

Topicality of the problem. Buildings consume 40 % of final energy, which also determines 36 % of greenhouse gas emissions in the EU. Due to the growing energy prices, tightening building energy performance and environmental requirements, growing needs of public comfort, we are faced with the problem that many buildings do not meet public needs. However building modernisation often is not attractive from the economical point of view or can not be executed due to the lack of financial resources. Therefore, modernisation of the existing buildings remains exceptionally important for sustainable development goals.

In existing buildings the biggest share of energy is consumed during their use phase. In order to reduce the energy consumption of the systems maintaining building microclimate and air quality parameters significant changes are required, i.e. simultaneous modernisation of the building envelopes and the above mentioned systems. This modernisation is a complex process, large in extent physically and financially. Therefore it is rarely performed. Sometimes the question is raised what is more appropriate – to demolish a building and to build a new one or to modernise it. Research shows that modernisation of buildings is more acceptable alternative in economic, energy and social terms. In order to increase attractiveness of building modernisation decision makers need alternative assessment criteria.

Many research studies are made in energy efficiency in buildings. Striving to optimize the environmental impact of buildings various simulation tools and

models are created by integrating different methods. Life cycle thinking application for buildings is also emphasised. Modernisation as a separate building life cycle phase is rarely considered. Modernisation of the building is examined as a static life cycle phase, i.e. during modernisation initial buildings characteristics created during construction phase are restored. Meanwhile, taking into account energy and environmental policy development and technological progress, it is clear that energy performance level of existing buildings facing inevitable modernisation in the future would not remain unchanged. In the thesis building modernisation analysis is carried out in order to assess also the impact of technological progress and regulatory changes on buildings life cycle.

Object of research – modernisation of building envelopes and systems maintaining microclimate and air quality parameters.

Aim and tasks of the work. Aim of the work is to compose public building modernisation assessment model allowing assessing building modernisation in terms of energy, environmental and physical deterioration criteria and to perform the analysis of impact of modernisation of building envelopes and systems maintaining microclimate and air quality parameters on building life cycle.

To achieve the aim of the work the following tasks are solved:

1. To perform critical review of buildings modernisation assessment methods and models used in practise and research while determining their strengths and weaknesses and examine scientific research carried out using the life cycle analysis applied to buildings.
2. To analyze the building as a technical system and its surrounding environment, energy, economic, environmental, social impact of building modernisation and the role of different stakeholders, while setting out the key criteria of building modernisation.
3. To evaluate thermal comfort in the analysis of building modernisation differentiating the benefit of restoration of normative temperature conditions.
4. To develop public building modernisation assessment model that allows assessing impact of modernisation of building envelopes and systems maintaining microclimate and air quality parameters on building life cycle, taking into account technological progress and state regulation factors.
5. Using the created model to carry out modernisation analysis of the selected buildings and to determine their optimal modernisation frequency.

Methodology of research. On the basis of principles of system analysis the building is analysed as a technical system revealing interconnections between the building and its surroundings (subsystems) and determining objective criteria for building modernisation. Considering the results of this analysis and using the life cycle and multiple criteria analysis techniques, the building modernisation evaluation model is developed. Bearing in mind the complexity of the building as a technical system and complications to investigate it experimentally the case studies research method was used as a research strategy. In building economical analysis thermal comfort is evaluated using Two-factor appraisal method, while supplementing it with thermal comfort criteria.

Scientific novelty

1. Based on system analysis and integration of the principles of life cycle analysis and building depreciation, a model for modernisation assessment of public building envelopes and systems maintaining the microclimate and air quality parameters was developed.

2. For the first time the optimal public building modernisation frequency was determined taking into account building life cycle energy consumption and greenhouse gas emissions.

3. Building life cycle was examined taking into account technological progress and the impact of state regulation on the building life cycle.

4. Modernisation phase of the building was not studied as a static one, when during the modernisation initial building characteristics created during construction phase are re-created, but as dynamic one when during each modernisation a higher energy performance value of the building is created.

5. The use of thermal comfort criterion for economic assessments of building modernisation was proposed.

Practical value. The results can be used in planning and expediency evaluations of building maintenance and modernisation as well as in defining requirements for buildings energy performance.

Defended propositions

1. Striving to assess objectively the demand and scope of building modernisation, in addition to the building physical depreciation and economic criteria it is appropriate to include life cycle energy consumption, pollutant emissions and thermal comfort into the system of the evaluation criteria.

2. Seeking to minimize building impact on environment it is appropriate to apply the life cycle approach in building operation and maintenance system,

thus optimising the impact of building envelopes and systems maintaining microclimate and air quality parameters on environment.

3. Balance of building physical and moral value, energy consumption, emissions and comfort can be achieved by planning building modernisation during its whole life cycle.

4. Building modernisation after it reaches total depreciation phase contradicts to the goals of long term energy conservation and building environmental impact reduction.

The scope of the scientific work. The scientific work consists of the introduction, 4 chapters, conclusions, list of literature, list of publications and addenda. The total scope of the dissertation is 130 pages, 41 picture, 6 tables and 2 addenda.

1. Review of building modernisation assessment methods and models

In this chapter building modernisation methods and models applied in practice and scientific research are analysed. Also building depreciation assessment in facilities management and real estate theories is analysed.

Various methods are applied in building modernisation assessment – from one criterion to comprehensive multi-criteria analysis, whole building life cycle analysing methods. Usually in practice economical methods are used to assess the benefits of building modernisation. Striving for a more comprehensive assessment, besides the economical benefits other methods are created that evaluate physical state, thermal comfort restoration benefits or losses due to the negative impact on environment and society of energy use. Seeking for a more comprehensive attitude towards buildings impact on environment and economy and striving to create buildings taking into account the concept of sustainable development life cycle analysis is used.

Simulation tools and models based on different methods are created to facilitate building design, assessment and decision making. From simple recommendations for decision makers, tools based on audits and assessment of return of investments to complex models based on multi-criteria analysis, requiring application of different methods to determine different criteria are used to assess and analyse buildings and their modifications.

A building is modernised when it reaches a certain level of depreciation and it is not possible to ensure its compliance with essential requirements for buildings. In real estate theory building depreciation is assessed according to the criteria of its physical depreciation and costs of restoration of physical characteristics. From the economical point of view such approach is correct.

But this is the main reason why building modernisation process is quite slow. However it is acknowledged that more attention has to be paid to the building maintenance and the demand for advanced building operation and maintenance models is emphasized.

2. System analysis of building and its surrounding environment

In this chapter the system under consideration (building and its surrounding environment) is analysed. Sustainable development policy, building energy performance regulation, energy consumption of existing buildings and new building concepts are reviewed. The impact of energy efficiency improvement in buildings, factors and criteria influencing selection of energy saving measures and the role of the interested parties are analysed.

Building is a complex system, composed of the set of technical systems, which is influenced by different fields of economy and science. Therefore such system should be analysed using system analysis. The building is composed of two subsystems – active and passive technical systems. They create required microclimate and indoor air quality, i.e. ensures the main function of the building. To ensure its function the building has to be supplied with the energy from electricity and heat production systems, building construction goods and services have to be provided. Building operation and maintenance causes waste and pollution. All those separate systems compose an over system called building energy supply system. Building energy supply system and its elements are affected by surrounding environment factors – geographical and climatic, technological progress, state policy and regulation which herewith are interrelated. One of the main elements of building surrounding is the user, to whom the main function of the building is applied and who raise particular requirements to its quality. Therefore while analysing building and seeking to take rational decisions it is reasonable to take into account relationship between different systems.

While setting goals of improvement of buildings energy efficiency it is necessary to identify the benefits of attainment of these goals. Impact of energy efficiency improvement in buildings can be evaluated from different aspects – technological, energy, environmental and social. One of the main goals of energy efficiency improvements in buildings is the increase of thermal comfort. To assess thermal comfort it was proposed to supplement Two-factor appraisal method by dividing the investments into energy efficiency into investments into energy saving and investments into comfort improvement (Užšilaiytė and Martinaitis 2007).

Scope of implementation of the energy efficiency measures depends on the priorities of stakeholders and factors influencing their decisions. Taking into account the main goals of stakeholders they can be divided into three categories: state, end-user and business.

Seeking to ensure qualitative building functioning and compliance with users' demands, permanent systemic building maintenance is required. At present in practice building modernisation demand is assessed on the basis of physical depreciation and economical criteria. However building modernisation is beneficial from energetic, environmental and social point of view. Therefore decision makers need alternative criteria in order to increase building modernisation attractiveness. Besides economic ones the main stakeholders' criteria determining decision to invest into building modernisation are thermal comfort improvement, energy consumption and emissions reduction, building depreciation reduction and increase of building value.

3. Composition of building modernisation assessment model

In this chapter the created model for assessment of building envelopes and microclimate and air quality parameters maintaining systems modernisation (hereinafter – Model) is presented. Mathematical model is composed according to the principles of system analysis and applying one of the system analysis fields – life cycle analysis. Multi criteria method is used for decision making.

The model is based on the concept of long-term building value conservation, when permanent systemic building maintenance ensures retainment of proper building physical and moral value. Modernisation is an important component of building maintenance system. During modernisation building physical and moral value is restored and energy performance is improved simultaneously. Striving to maintain certain level of building physical and moral value, minimise building energy consumption and pollution and ensure proper comfort, the building modernisation has to be planned in advance and executed in particular time intervals. Therefore as a main criterion to assess demand and scope of building modernisation during its life cycle, the periodicity of building modernisation is selected. Building modernisation periodicity is determined on the basis of minimal energy consumption and impact on environment during building life cycle. The technological progress and state regulation evaluation is introduced as well. Principal scheme of the Model is presented in Fig. 1.

Assessment of building modernisation periodicity is divided into four stages. In the first stage analysis of building under consideration is performed. In the second stage surrounding environment is analysed and assumptions and

alternatives are formulated. In the third stage calculations of alternatives are performed using technological, energy and environmental Model components. In the fourth stage results of calculations are analysed and the decision made.

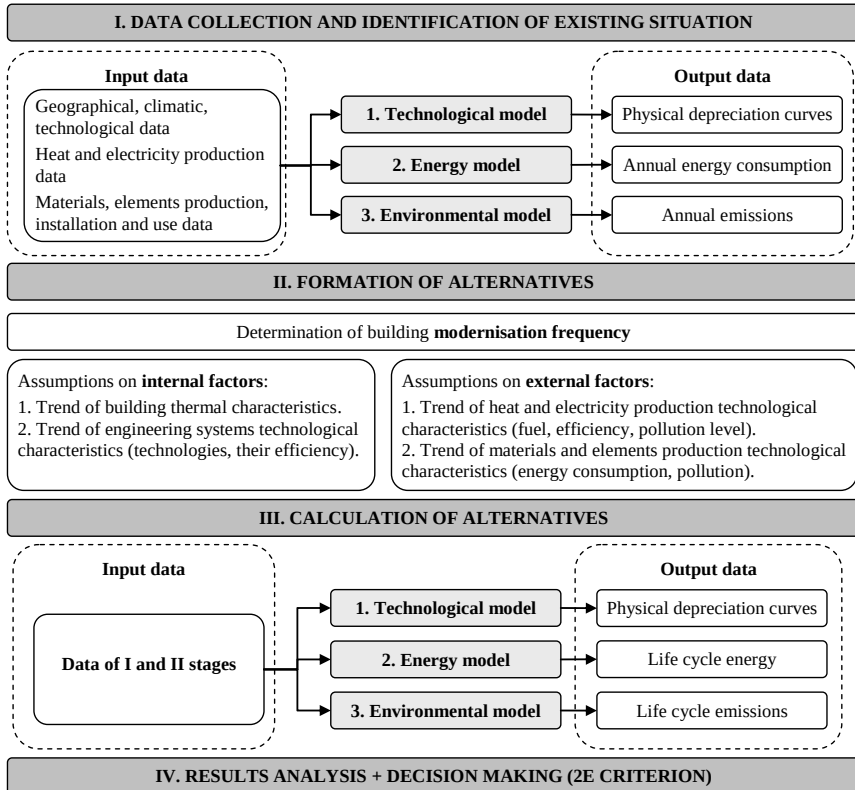


Fig. 1. Principal scheme of building modernisation assessment model

In the Model building life cycle is divided into technological, energy and environmental cycles afterwards combining them for decision making. First of all technological building life cycle is composed. In technological cycle building parts and elements under consideration are determined, their lifetimes are estimated, and depreciation characters are selected. After composing technological life cycle building modernisation intervals are estimated. In these intervals selected criteria calculations are performed using energy and environmental Model components.

Energy and environmental model components are composed according to the general principles of life cycle analysis. Building energy life cycle shows primary energy consumption during building life cycle taking into account all flows of fuel, heat, electricity for building heating, ventilation, hot water preparation as well as for building envelopes installation and modernisation. In building environmental life cycle greenhouse gas emissions emitted due to functioning of building systems under consideration are evaluated.

Final results of building modernisation alternatives under consideration are assessed using two criteria – total building life cycle energy consumption and emissions. To make final decision those criteria have to be prioritised. 3E method is used for this purpose, transforming it into 2E criteria (i.e. expenses component is eliminated).

4. Application of building modernisation assessment model

Seeking to verify applicability of the Model, in this chapter two buildings modernisation assessment is performed and optimal periodicity and scope of building modernisation is determined. The optimal periodicity and the scope of building modernisation are determined simulating different scenarios of the changes of state building thermal characteristics regulation and forecasting energy efficiency trends of building engineering systems and energy production systems. While calculating 2E criterion it was assumed that building life cycle energy consumption and emissions are equally important.

Two standard school buildings were selected for the analysis. The 1st building (6228 m², number of pupils – 1284) was designed in 1974. The 2nd building (2306 m², number of pupils – 216) was designed in 1986.

Final results of the analysis are presented in Fig. 2 and 3.

Optimal modernisation periodicity of the 1st building is 19 years, of the 2nd building – 20 years (i.e. 4 times per considered building life time) when standard heat transmission coefficients of the building envelopes become lower by 50 % every 10 years.

Results of both buildings are similar. Although thermal characteristics of the 1st buildings in the construction phase are worse than that of the 2nd building, the higher embodied energy consumption of the 2nd building determines similar results.

The main elements influencing optimal building modernisation periodicity are building size, durability of building constructions and engineering systems and change of electricity demand. Building size determines the share of embodied energy in total life cycle energy consumption. The higher is the ratio between building envelopes area and building area, the bigger is the share of

embodied energy that reduces benefits of modernisation. The increase of electricity demand after building modernisation has a reverse effect. When electricity demand increases and subsequently the pollution due to electricity production is increased, optimal building modernisation periodicity becomes rarer.

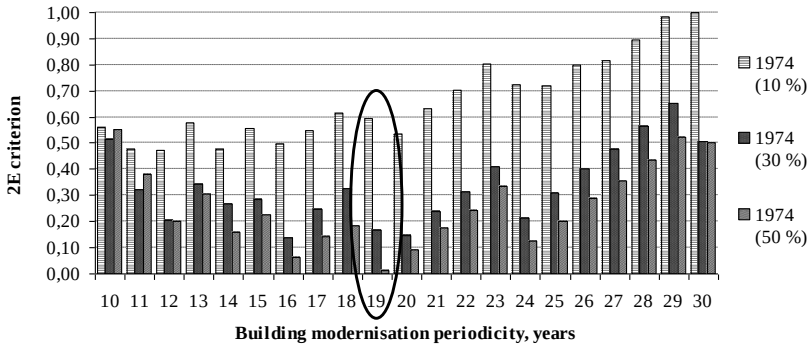


Fig. 2. 1st building 2E criterion

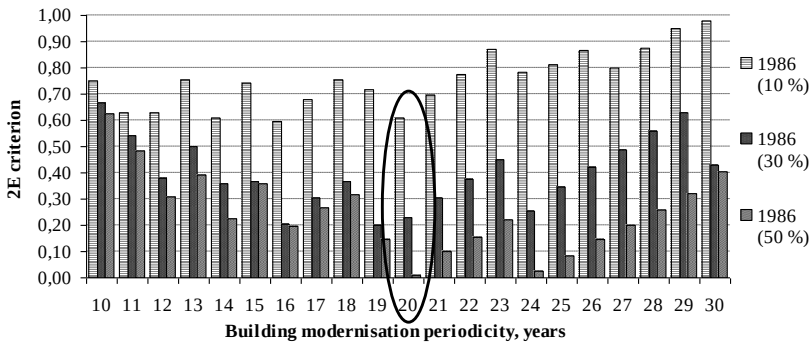


Fig. 3. 2nd building 2E criterion

Seeking to verify reliability of the results and to estimate what was the impact made by the change of different variables for which assumptions were made, sensitivity analysis was conducted.

Sensitivity analysis showed that the initial building energy performance made the biggest impact on the results. While verifying the impact of initial energy performance, calculations were made for the cases if the building under

consideration in the construction phase complied with requirements of regulation 2005 for building thermal characteristics and if the efficiency level of systems maintaining building microclimate and indoor air quality corresponded to the level of that period. If the building was constructed according to regulation 2005, the lowest 2E criteria would be obtained when building modernisation periodicity is 24 years (i.e. 3 times per considered building life time) and after the first modernisation would reach passive house requirements.

Pollution indicator of heat production also has a significant impact on optimal building modernisation periodicity, when building thermal characteristics are low. When pollution due to heat production is growing, energy and pollution criteria become equally important, i.e. more frequent modernisation becomes reasonable. When pollution is decreasing embodied energy acquires significant impact. Embodied energy has a negative impact on building modernisation results if the used energy is greenhouse gas neutral.

In case of pollution indicator of electricity production the obtained results are opposite. In contrast to heat production, increase of pollution due to electricity production makes the optimal modernisation periodicity rarer. This is related to the fact that while changing heating and ventilation systems installed at the construction stage of the building electricity consumption is increased and this determines the increase of pollution.

Fig. 4 and 5 presents the comparison of the best results with the situation if the buildings were modernised every 30 years minimally improving their energy performance.

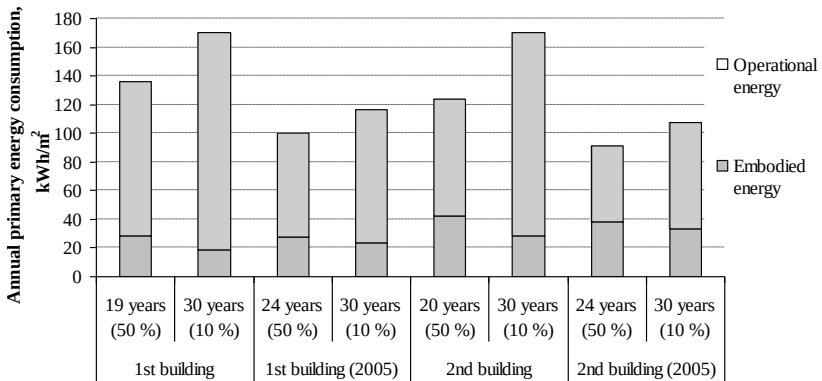


Fig. 4. Comparison of energy consumption of the best alternatives with cases when buildings modernisation periodicity is 30 years

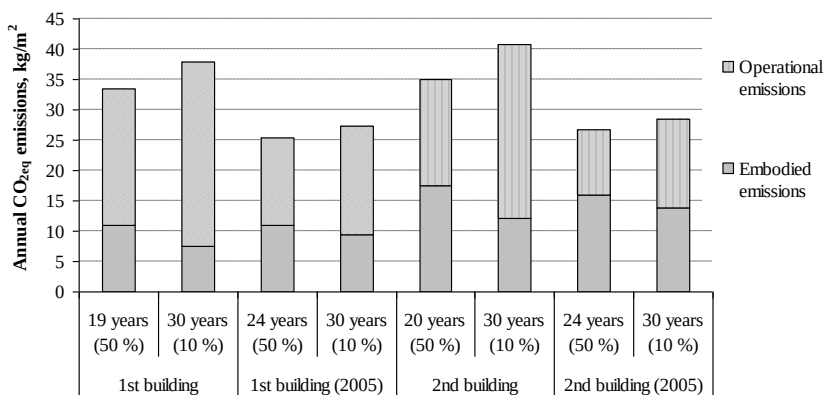


Fig. 5. Comparison of emissions of the best alternatives with cases when buildings modernisation periodicity is 30 years

Comparing the optimal frequency of the building modernisation with the case if the building was modernised every 30 years, minimally improving its thermal characteristics, in case of the 1st building 25 % of primary energy would be saved and 14 % of greenhouse gas emissions would be reduced. In case of the 2nd building it would be possible to save 37 % of primary energy and reduce greenhouse gas emissions by 16 %. If the same building was built according to the regulation 2005 in case of the 1st building 16 % of primary energy would be saved and 7 % of greenhouse gas emissions would be reduced. In case of the 2nd building it could be possible to save 17 % of primary energy and reduce greenhouse gas emissions by 7 %.

General conclusions

1. Buildings make significant impact on inefficient use of energy and environment. However in practise the concept of building value conservation is based on economical and physical depreciation criteria. During the review of building life cycle research it was identified that building modernisation stage is evaluated not taking into account the impact of the inevitable technological progress and state building energy performance regulation policy on building life cycle.

2. Analysis showed that besides economical and physical depreciation criteria, energy efficiency, pollution reduction and thermal comfort improvement there are the main stakeholders' criteria determining decisions of building modernisation.

3. From the point of view of traditional economics building modernisation is often not attractive. Additional methodological problems are raised by the situation when normative temperature conditions were not ensured in building before modernisation. The proposed method allows evaluation of benefits of restoration of thermal comfort in economical calculations while separating it from the physical state reestablishment and energy saving benefits.

4. In this work a building modernisation assessment model is composed allowing to analyse building modernisation impact on change of building physical state, life cycle energy consumption and pollution emissions and thermal comfort. The model allows taking into account impact of technological progress and state regulation on its life cycle and determining the optimal periodicity and scope of building modernisation.

5. While using the model a case study research of two standard school buildings was performed. Scope and optimal periodicity of building modernisation was determined simulating different scenarios of the change of state regulation requirements for thermal characteristics and forecasting energy efficiency trends of building engineering systems and energy production. Results of simulation shows that:

- optimal modernisation intervals of the buildings meeting requirements of 1974 and 1986 whose initial annual heat consumption equals to 257 and 219 kWh/m², are respectively 19 and 20 years or 4 times during their lifetime. Comparing the results of optimal frequency case of the building modernisation with the case if the building was modernised every 30 years, minimally improving its thermal characteristics, in case of the 1st building app. 25 % of primary energy would be saved and app. 14 % of greenhouse gas emissions would be reduced. In case of the 2nd building it would be possible to save app. 37 % of primary energy and reduce greenhouse gas emissions app. by 16 %;

- in case of the same buildings if they were constructed complying with the 2005 regulation, optimal building modernisation frequency is 24 years or 3 times during its lifetime. Comparing the results of optimal frequency case of the building modernisation with the case if the building was modernised every 30 years, minimally improving its thermal characteristics, in case of the 1st building app. 16 % of primary energy would be saved and app. 7 % of greenhouse gas emissions would be reduced. In case of the 2nd building it could be possible to save app. 17 % of primary energy and reduce greenhouse gas emissions app. by 7 %.

6. Research showed that the main elements influencing optimal building modernisation periodicity is building size, durability of building construction and engineering systems and change of electricity demand. The higher is the ratio between building envelopes area and building area, the bigger is the share of embodied energy. This reduces benefit of modernisation. The reverse effect was observed in the increase of electricity demand after building modernisation. Optimal building modernisation periodicity becomes rarer when after modernisation the electricity demand increases and subsequently the pollution due to electricity production also increases.

7. After the conduction of sensitivity analysis the tendency was estimated that pollution due to heat production has a significant impact on building modernisation periodicity. When pollution due to heat production is growing, energy and pollution criteria become equally important, i.e. more frequent modernisation becomes reasonable. When pollution is decreasing the impact of embodied energy may prove significant. Therefore more frequent building modernisation becomes less reasonable.

List of Published Works on the Topic of the Dissertation In the reviewed scientific periodical publications

Užšilaitytė, L.; Martinaitis, V. 2010. Pastato renovacijos periodiškumo įtaka jo gyvavimo ciklo energijos sąnaudoms [Impact of building renovation on its life cycle energy consumption], *Energetika* Vol. 56, No 2: 146–153. ISSN 0235-7208. (Inspec).

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Issues "CYSENI 2009". May 28–29, 2009, Kaunas, Lithuania. [CD-ROM]. Lithuanian Energy Institute, 11 p. ISSN 1822-7554.

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Užšilaitytė, L.; Martinaitis, V. 2006. Energijos taupymo projektų vertinimas, naudojant daugiakriterinės analizės metodą [Evaluation of energy saving projects using multi-criteria analysis], iš *Respublikinė konferencijos „Inžinerinės sistemos“, įvykusios Vilniuje 2006 m. balandžio 27–28 d. medžiaga* [Proceedings of the Republican Conference "Buildings Engineering Systems", held in Vilnius on April 27–28, 2006]. Vilnius: Technika, 3–9. ISBN 9986-05-971-2.

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VIEŠOJO NAUDOJIMO PASTATŲ ENERGETINIO MODERNIZAVIMO MODELIS

Problemos formulavimas. Modernizavimas yra svarbus pastato naudojimo ir priežiūros sistemos komponentas, kurio metu kompleksiskai atkuriami pastato fizinė ir moralinė vertė, didinamas energijos vartojimo efektyvumas, šiluminis komfortas bei mažinamas neigiamas poveikis aplinkai. Tačiau pastatų modernizavimo poreikis ir apimtis šiuo metu vertinama, vadovaujantis tik ekonominiais ir fizinio nusidėvėjimo kriterijais. Toks požiūris yra nepakankamas, siekiant ilgalaikio pastato vertės išlaikymo ir užtikrinant pastatų atitiktį vienam iš esminių reikalavimų statiniui – energijos taupymui ir šilumos išsaugojimui.

Šiame darbe tiriama, kokie kriterijai taikytini objektyviam viešojo naudojimo pastatų modernizavimo vertinimui ir kokią įtaką pastato gyvavimo ciklui daro sistemingas, kompleksinis pastato atitvarų ir mikroklimato bei oro kokybės parametrus palaikančių sistemų modernizavimas, atsižvelgiant į reikalavimų pastatų energiniam naudingumui griežtėjimo tendencijas ir technologinę pažangą.

Darbo aktualumas. Pastatuose suvartojama 40 % galutinės energijos, kas taip pat nulemia 36 % visų šiltnamio efektą sukeliančių dujų emisijų Europos Sąjungoje. Brangstant energijos ištekliais, griežtėjant pastatų energinio naudingumo ir aplinkosauginiams reikalavimams, augant visuomenės komforto poreikiams, susiduriama su problema, kad didelė šių pastatų dalis nebeatitinka šiuolaikinių, o atskirais atvejais ir minimalių, visuomenės poreikių. Tačiau pastatų modernizavimas dažnai yra nepatrauklus ekonomiškai arba dėl finansinių išteklių stokos nevykdomas. Todėl esamų pastatų modernizavimo klausimas išlieka išskirtinai svarbus, siekiant trumpalaikių ir ilgalaikių darnaus vystymosi tikslų.

Didžiausias kiekis energijos esamuose pastatuose suvartojamas jų naudojimo metu. Siekiant sumažinti energijos sąnaudas pastato mikroklimato ir oro kokybės parametrus palaikančiose sistemose, reikalingi esminiai pakeitimai, t. y. vienalaikis pastato atitvarų ir minėtų sistemų modernizavimas. Šis modernizavimas yra sudėtingas procesas, didelės apimties fiziškai ir finansiškai, todėl pastato gyvavimo laikotarpiu vyksta retai. Kartais keliamas klausimas, kas tikslingiau – pastatus nugriauti ir statyti naujus ar juos modernizuoti. Moksliniai tyrimai rodo, kad pastatų modernizavimas yra priimtinesnė alternatyva ekonominiu, energetiniu ir socialiniu požiūriais. Siekiant didinti pastatų modernizavimo patrauklumą, sprendimus priimančioms asmenims reikalingi alternatyvūs vertinimo kriterijai.

Dėl energijos vartojimo efektyvumo didinimo pastatuose atliekama daug tyrimų. Siekiant optimizuoti pastatų poveikį aplinkai, integruojant skirtingus metodus, kuriamos įvairios modeliavimo priemonės ir modeliai, akcentuojamas gyvavimo ciklo požiūrio taikymo tikslingumas. Moksliniuose tyrimuose modernizavimas, kaip atskiras pastato gyvavimo ciklo tarpsnis, nagrinėjamas retai. Atliktuose tyrimuose modernizavimas nagrinėjamas kaip statinis pastato gyvavimo ciklo tarpsnis, t. y. modernizavimo metu atkuriamos pastato statybos metu sukurtos charakteristikos. Tuo tarpu, atsižvelgiant į energetikos ir aplinkosaugos politikos vystymąsi bei technologinę pažangą, akivaizdu, kad dabartinių pastatų, ateityje sulauksiančių neišvengiamo modernizavimo, energinio naudingumo lygmuo neišliks nepakitęs. Todėl šiame darbe pastato modernizavimo analizė atliekama, siekiant įvertinti technologinės pažangos ir valstybinio reguliavimo kitimo įtaką pastato gyvavimo ciklo sąnaudoms.

Darbo tyrimų objektas – pastato atitvarų ir mikroklimato bei oro kokybės parametrus palaikančių sistemų modernizavimas.

Darbo tikslas ir uždaviniai. Darbo tikslas – sudaryti viešojo naudojimo pastato modernizavimo vertinimo pagal energetinius, aplinkosauginius, pastato nusidėvėjimo kriterijus modelį ir atlikti pastatų atitvarų ir mikroklimato bei oro kokybės parametrus palaikančių sistemų modernizavimo įtakos pastato gyvavimo ciklo sąnaudoms analizę.

Darbo tikslui pasiekti darbe sprendžiami šie uždaviniai:

1. Atlikti praktikoje ir moksliniuose tyrimuose naudojamų pastatų modernizavimo vertinimo metodų ir modelių kritinę apžvalgą, vertinant jų trūkumus ir privalumus ir išnagrinėti mokslinius tyrimus, kuriuose gyvavimo ciklo analizė buvo taikoma pastatams.
2. Išanalizuoti pastatus kaip techninę sistemą ir juos supančią aplinką, pastatų modernizavimo energetinį, ekonominį, aplinkosauginį, socialinį poveikį ir atskirų suinteresuotų grupių vaidmenį nustatant pagrindinius tikslingus pastatų modernizavimo vertinimo kriterijus.
3. Pastatų modernizavimo analizėje įvertinti šiluminį komfortą, atskiriant norminių temperatūrinių sąlygų atstatymo naudą.
4. Sudaryti viešojo naudojimo pastato modernizavimo vertinimo modelį, leidžiantį įvertinti pastato atitvarų ir mikroklimato bei oro kokybės parametrus palaikančių sistemų modernizavimo įtaką pastato gyvavimo ciklui, atsižvelgiant ir į technologinės pažangos bei valstybinio reguliavimo veiksmus.
5. Naudojant sudarytą modelį, atlikti pasirinktų pastatų modernizavimo analizę ir nustatyti optimalų jų modernizavimo periodiškumą.

Tyrimų metodika. Remiantis sisteminės analizės principais atliekama pastato kaip techninės sistemos analizė, kurios metu atskleidžiami pastato ir jį supančios aplinkos (viršsistemių) tarpusavio ryšiai, nustatomi objektyviam pastatų modernizavimo vertinimui taikytini kriterijai. Atsižvelgiant į šios analizės rezultatus, naudojant gyvavimo ciklo ir daugiakriterinės analizės metodus, sudaromas pastato modernizavimo vertinimo modelis. Naudojant šį modelį, atliekama pasirinktų pastatų modernizavimo analizė. Atsižvelgiant į pastato kaip techninės sistemos sudėtingumą ir problematiškumą jį tirti eksperimentiškai, darbe kaip tyrimo strategija naudojamas atvejo studijos tyrimo metodas. Pastatų ekonominėje analizėje šiluminis komfortas įvertintas, naudojant Dviejų faktorių metodą, dalinantį bendrąsias investicijas į investicijas į energijos vartojimo efektyvumą ir pastato fizinės būklės gerinimą, papildant jį šiluminio komforto sąlygų gerinimo dedamąja.

Mokslinis naujumas

1. Remiantis sisteminės analizės principais ir integruojant gyvavimo ciklo analizės bei pastato nusidėvėjimo kitimo principus, sudarytas viešojo naudojimo pastato atitvarų ir mikroklimato bei oro kokybės parametrus palaikančių sistemų modernizavimo vertinimo modelis.

2. Pirmą kartą nustatytas optimalus viešojo naudojimo pastato modernizavimo periodiškumas, atsižvelgiant į pastato gyvavimo ciklo energijos sąnaudas ir šiltnamio efektą sukeliančių dujų emisijų kiekius.

3. Pastato gyvavimo ciklo sąnaudos nagrinėtos vertinant technologinės pažangos ir valstybinio reguliavimo poveikį pastato gyvavimo ciklui.

4. Pastato modernizavimo tarpsnis nagrinėtas ne kaip statinis, kai modernizavimo metu atkuriamos pirminės statybos metu sukurtos pastato charakteristikos, o kaip dinaminis, kai kiekvieno modernizavimo metu sukuriami didesnio energinio naudingumo pastato vertė.

5. Pasiūlytas šiluminio komforto kriterijaus įvertinimo būdas ekonominiuose pastatų modernizavimo naudos vertinimuose.

Praktinė reikšmė. Darbo rezultatai gali būti panaudoti pastatų modernizavimo ir priežiūros planavime ir tikslingumo vertinimuose bei nustatant reikalavimus modernizuojamų pastatų energiniam naudingumui.

Ginamieji teiginiai

1. Siekiant visapusiško ir objektyvaus pastato modernizavimo poreikio ir apimties nustatymo, į vertinimo kriterijų sistemą šalia fizinio nusidėvėjimo ir ekonominių kriterijų tikslinga įtraukti pastato gyvavimo ciklo energijos sąnaudų, teršalų emisijų ir šiluminio komforto kriterijus.

2. Siekiant minimizuoti pastatų poveikį aplinkai, pastatų naudojimo ir priežiūros sistemoje tikslinga taikyti gyvavimo ciklo požiūrį, tuo būdu optimizuojant pastato atitvarų ir mikroklimato bei oro kokybę palaikančių sistemų modernizavimo bendrąjį poveikį aplinkai.

3. Pastato fizinės ir moralinės vertės, energijos sąnaudų, aplinkos taršos ir komforto subalansavimas gali būti pasiektas, planuojant pastato modernizavimą per visą jo gyvavimo ciklą.

4. Pastato modernizavimo vykdymas tik po to, kai jis pasiekia „visiško nusidėvėjimo“ tarpsnį, prieštarauja ilgalaikio energijos išteklių tausojimo ir pastatų poveikio aplinkai mažinimo tikslams.

Darbo apimtis. Darbą sudaro bendra darbo charakteristika, 4 skyriai, išvados, literatūros sąrašas, publikacijų sąrašas ir priedai. Bendra disertacijos apimtis – 130 puslapių, 41 iliustracija, 6 lentelės ir 2 priedai.

Pirmajame skyriuje nagrinėjami praktikoje ir moksliniuose tyrimuose taikomi pastatų modernizavimo vertinimo metodai ir modeliai. Taip pat apžvelgiamas pastatų nusidėvėjimo vertinimas pastatų ūkio valdymo ir nekilnojamojo turto teorijose.

Antrajame skyriuje aprašoma darbe tyrinėta sistema (pastatas ir jį supanti aplinka) ir analizuojamos atskiros sistemą sudarančios posistemės.

Trečiajame skyriuje pateikiamas sukurtas pastatų modernizavimo vertinimo modelis.

Ketvirtajame skyriuje, naudojant sukurtą pastatų modernizavimo vertinimo modelį, atliekama dviejų mokyklų pastatų modernizavimo analizė.

Bendrosios išvados

1. Pastatų naudojimas daro žymų poveikį energijos išteklių netausiam vartojimui ir neigiamą poveikį aplinkai, bet praktikoje jų vertės išlaikymo koncepcija remiasi ekonominiais ir pastato fizinio nusidėvėjimo vertinimo kriterijais. Apžvelgus pastatų gyvavimo ciklo tyrimus, nustatyta, kad pastato modernizavimo tarpsnis vertinamas neatsižvelgiant į neišvengiamą technologinės pažangos ir valstybinę pastatų energinio efektyvumo politiką išreiškiančio reglamentavimo įtaką pastato gyvavimui.

2. Atlikta analizė parodė, kad be ekonominių ir fizinio nusidėvėjimo kriterijų, energijos vartojimo, taršos mažinimas ir šiluminio komforto padidinimas yra pagrindiniai kriterijai, lemiantys suinteresuotų grupių pastatų modernizavimo sprendimus.

3. Klasikinės ekonomikos požiūriu pastatų modernizavimas dažnai yra nepatrauklus. Papildomų metodinių problemų ekonominiuose vertinimuose kelia padėtis, kai pastate iki modernizavimo nebuvo užtikrinamos norminės

temperatūrinės sąlygos. Šiame darbe pasiūlytas metodas leidžia įvertinti šiluminio komforto atstatymo naudą ekonominiuose skaičiavimuose, atskiriant ją nuo pastato fizinės būklės atstatymo ir energijos taupymo naudos.

4. Darbe sudarytas pastato modernizavimo vertinimo modelis, leidžiantis nagrinėti modernizavimo poveikį pastato fizinės būklės kitimui, jo gyvavimo ciklo pirminės energijos sąnaudoms ir teršalų emisijoms bei šiluminiam komfortui. Modelis leidžia įvertinti technologinės pažangos ir valstybinio reguliavimo įtaką pastato gyvavimo ciklui ir nustatyti optimalų pastato modernizavimo periodiškumą ir apimtį.

5. Naudojant sudarytą modelį, atlikta dviejų tipinių mokyklų pastatų atvejo analizė ir nustatytas optimalus pastatų modernizavimo periodiškumas bei apimtis. Optimalus pastatų modernizavimo periodiškumas ir apimtis nustatyti, modeliuojant skirtingus pastatų atitvarų šiluminių charakteristikų valstybinio reglamentavimo kitimo scenarijus ir prognozuojant pastato inžinerinių sistemų bei energijos gamybos efektyvumo kitimo tendencijas. Atlikto modeliavimo rezultatai rodo, kad:

- optimalus pastatų, atitinkančių 1974 m. ir 1986 m. statybos reikalavimus, kurių pradinės metinės šilumos sąnaudos atitinkamai sudarė 257 ir 219 kWh/m², modernizavimo periodiškumas yra atitinkamai 19 ir 20 metų arba 4 kartai per gyvavimo laikotarpį. Lyginant optimalaus pastato modernizavimo periodiškumo atvejo rezultatus su atveju, jeigu pastatas būtų modernizuojamas kas 30 metų, minimaliai gerinant jo šilumines charakteristikas, gaunama, kad pirmajame pastate būtų galima sutaupyti apie 25 % pirminės energijos ir apie 14 % sumažinti šiltnamio dujų emisijas, antrajame pastate – sutaupyti apie 37 % pirminės energijos ir apie 16 % sumažinti šiltnamio dujų emisijas;

- tų pačių pastatų, atitinkančių 2005 m. normas, optimalus pastato modernizavimo periodiškumas yra 24 metai arba 3 kartai per gyvavimo laikotarpį. Lyginant optimalaus pastato modernizavimo periodiškumo atvejo rezultatus su atveju, jei pastatas būtų modernizuojamas kas 30 metų, minimaliai gerinant jo šilumines charakteristikas, gaunama, kad pirmajame pastate būtų galima sutaupyti apie 16 % pirminės energijos ir apie 8 % sumažinti šiltnamio dujų emisijas, antrajame pastate – sutaupyti apie 18 % pirminės energijos ir apie 7 % sumažinti šiltnamio dujų emisijas.

6. Atlikti tyrimai parodė, kad pagrindiniai elementai, darantys poveikį optimaliam pastato modernizavimo periodiškumui, yra pastato dydis, konstrukcijų ir inžinerinių sistemų ilgaamžiškumas, elektros energijos poreikio kitimas. Kuo didesnis santykis tarp pastato atitvarų ploto ir pastato ploto, tuo didesnė to pastato ikūnytųjų energijos sąnaudų dalis, dėl ko mažėja pastato modernizavimo nauda. Optimalus pastato modernizavimo periodiškumas retėja,

kai po pastato modernizavimo išauga elektros energijos poreikis ir dėl to padidėja dėl elektros energijos gamybos susidaranti tarša.

7. Atlikus gautų rezultatų jautrumo analizę atskirų kintamųjų kitimui išryškėjo tendencija, kad didžiausią įtaką optimaliam pastato modernizavimo periodiškumui daro tarša, susidaranti dėl pastato naudojimui reikalingos šilumos gamybos. Didėjant šilumos gamybos taršos rodikliui taršos ir energijos sąnaudų kriterijai tampa vienodai svarbūs, todėl dažnėja pastato modernizavimo poreikis. Mažėjant šilumos gamybos taršos rodikliui, taršos kriterijaus rezultatams didesnę įtaką daro ikūnytosios emisijos, todėl dažnesnis pastato modernizavimas tampa mažiau tikslingas.

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