VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

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MODEL OF SUSTAINABLE MANAGEMENT OF BUILDING ENERGY PERFORMANCE CHARACTERISTICS

SUMMARY OF DOCTORAL DISSERTATION

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Introduction

Scientific problem – the State of art evaluation of buildings and the measures of renovation is understandable as continuous process, not only as onetime operation.

Continually updated decision-making tools already developed, but they are mostly used by economic criteria. However, the growing awareness of the broad range of building refurbishment (not just economic) benefits, but the lack of more general opinions on what criteria should be evaluated. Most scientists agree that the building assessment must be carried out in accordance with any of the criteria, covering a range of building-related areas: improved conditions in the premises, minimizing the environmental impact, change of building state in its life cycle. Concept of sustainable development is often mentioned, but it is descriptive of the evaluation criteria for building search continues in practice and science.

The existing building conditions assessment methods for energy-saving measures for sustainable evaluation criteria, decision-making and continuous building management tools are analyzed in this dissertation.

Topicality of the problem – construction of new buildings in Europe is only a small part of all the buildings. The main consumer of energy in the building sector is the existing buildings, which account for about 99% of the building sector.

Becoming more stringent EU requirements are tightening for new buildings and the gap between the energy consumption in existing and new buildings is increasing. Continuous management (supervision) of existing buildings, the improvement of its energy efficiency is becoming more important in the context of tightened EU requirements and development of technology.

In this environment the demand of better comfort conditions, information about energy consumption, the reduction of energy use, increase. On the other hand upraise of technological capabilities (Building automation control systems (BACS), modeling and decision-making tools) allow conditions and demand to continuous management of building energy performance characteristics. More often buildings in the design stage are modeled by computer modeling tools to achieve a lower energy demand. Meanwhile, the modeling tools for existing buildings to assess opportunities for reduction of energy consumption are rare.

Scientists of electronics and automation usually tackle the problem of continual supervision of energy consumption. Their studies usually examine reliability of the sensors and controllers, the elimination of errors, data

processing and storage problems. The energy efficiency in these studies is understood as maximally smoothly working energy systems without touching their own improvement.

It also created a continuous management tools used to assess the potential for building renovations, but the choice of one or only a few areas of assessing criteria. Concept of sustainable development is increasingly encompasses all areas of life and should be used for the assessment of buildings, the renovation, management and supervision. Thus, the state of art building's site management should be organized on the basis of not only economic benefits, but also assessing the social and environmental benefits – the evaluation of the concept of sustainable development principle.

Object of the work – energy performance characteristics of public buildings, the influence of change of characteristics to continual management, sustainable criteria for characteristics evaluation. Continual management of building energy performance characteristics is understandable, decisions formed under actual information about building condition basis for preventive maintenance.

Aim of the work – to create the algorithm of expert system for management of building energy performance characteristics which sustainably evaluate the potential of building renovation and more effective energy consumption.

Tasks of the work

It was selected to solve these tasks to achieve the aim of the work:

1. To take cognizance and analyze existing energy audits, building assessment, monitoring, and energy analysis techniques. To analyze a building's energy consumption, their dependence on the various factors used in the energy balancing algorithms.
2. To create the balance equation for analysis of building energy performance characteristics, this should be applicable for continual management of the building.
3. To analyze evaluation methods for energy efficiency measures of buildings. To review the criteria used by scientists for evaluation of the energy efficiency measures, and criteria in coherence with the components of sustainable development. To create a set of criteria assessing sustainable point of view for energy efficiency measures with attributes expressing the criteria set.

4. To create multi-criteria method for sustainable evaluation of energy efficiency measures for the building and for packets formation of the evaluated measures.

5. Develop the algorithm for model of sustainable management of building energy performance characteristics, in which building performance characteristics are analyzed, the energy efficiency measures are proposed, their impact on the environment and building is assessed by sustainability criteria.

Methodology of research. Actual energy consumption of the building is analysed after recalculation to specific consumption and the balance equation is constructed by specific consumption components. Balance equation is constructed by the "bottom up" method starting from the end user, the objective is to ensure equality of comfort conditions in the building.

Energy efficiency measures are evaluated by multi-criteria method. The criteria are normalized by SAW method (*Simple Additive Weighting*). Sequential multi criteria methodology for evaluation energy efficiency measures and their packets formation is constructed by decision tree method.

Scientific novelty

New results for Energetics and Power Engineering science where got in the thesis:

1. The balance equation was created, for sustainable management of building energy performance characteristics on the already used balance equations
2. Criteria tree is created for sustainable evaluation of energy efficiency measures by general sustainability criterion, when in duration of life cycle the energy efficiency, environmental impact, economical rationality and comfort is assessed.
3. The algorithm developed by decision tree method for packets formation of energy efficiency measures for selection of the basic and additional list.
4. Model of management of sustainable energy performance characteristics was developed for continual supervision of energy performance characteristics and for improvement of its effectiveness.

Practical value. The results can be used for building maintenance planners, managers and modernization of buildings assessors for preparation of modernization plans for more efficient and better quality of building energy management in concept of sustainability principles.

Defended propositions

1. Specific energy consumption analysis allows dissociating from the influence of climatic conditions. For continual building management, evaluation of individual components it is necessary to examine energy balance equation, which consists of the components of specific energy consumption.
2. Sustainable assessment of energy efficiency measures should include not only energy-saving, environmental and economic benefits, but also the selected or required level of comfort in the premises. When analysis starts with a 'bottom-up' approach of the end user, the necessary level of comfort in the premises is provided. Sustainability should also be assessed point of view of the life cycle of the building.
3. Establishment of necessary measures and created method for grouping the measures simplify the decision making process and let to ensure comfort conditions after renovation.
4. The expert system, continually working on basis of actual energy and other resources consumption monitoring and analysis, increase the sustainability of building maintenance and resources consumption, lets to use the building more efficient, make decisions for building retrofit.

The scope of the scientific work. The scientific work consists of the introduction, 3 chapters, conclusions, list of literature, list of publications and addenda. The total scope of the dissertation – 84 pages, 27 pictures, 10 tables.

1. Review of evaluation methods of buildings and retrofit measures and of methods for continual monitoring

In this chapter the methods for evaluation of building energy consumption, renovation measures applied in practice and scientific research are analyzed. Also multi-criteria methods and application of continual improvement for building sector are analyzed.

The most accurate analysis of energy consumption is analysis based on actual consumption, but simulated detecting the differences, and eliminating the detected reasons. The main reason, which influence the difference of the results for energy consumption, researchers refer to occupants behavior.

Heat balance method and weighting-factor method are two basic methods to resolve the heating load or energy consumption. The heat balance method is more accurate, because the heat gains and heat fluxes from different energy systems inside the building can be evaluated. For this reason the new generation simulation programs for buildings energy use are based on heat balance method.

The evaluation and prioritization of EEM (Energy efficiency measures) depends on the chosen criteria. The most commonly used criterion is economical evaluation. Another popular criteria for evaluation of EEM is energy efficiency or energy saving. It is related with economic criteria, because without saving will be no financial benefit of implementation of EEM. So the measure which is economically feasible has energy savings as well. The energy efficiency criteria often is used together with criteria of environmental impact and in literature is presented as 2E criteria and with economic criteria 3E evaluation. Environmental and energy efficiency criteria usually are met Life cycle analysis (LCA).

When criteria are defined the clear structure and procedure for decision making should be defined. It is easier to implement energy efficiency measures to newly designed and constructed buildings than to old ones (already built ones). To assess their situation and adapt energy efficiency measures there is a need of deep knowledge and expertise of various specialists. This raises the need for this expertise to organize, generate the optimal, best individually suited kits of building energy efficiency measures. Multi criteria decision making-separate area of science and its application in choosing correct building EEM requires interdisciplinary approach. Decision tree (DT) is a versatile information clustering and classification tool used in a wide range of scientific and industrial fields.

Summarizing the described studies with different purposes of EEM evaluation and different criteria, the conclusion is that to evaluate EEM in sustainable and universal aspect the complex of criteria should be used, which involve energy efficiency, environmental impact, economical rationality, comfort and life cycle duration. It is more appropriate and clear to perform the sequential and cyclical decision making by decision tree method. The model of sustainable management of building energy performance characteristics was created, which is based on energy consumption analysis by heat balance equation and DT method for decision making by five sustainability criteria.

2. Model of sustainable management of building energy performance characteristics

The model of sustainable management of building energy performance characteristics (SMoBEPC), which was created, is presented in this chapter. This model is designed for continual management and supervision of building and for planning the possibility of building retrofit.

The review of methods of buildings energy performance assessment and continual improvement open three parts for analysis for construction of model

for sustainable management of building energy performance characteristics. The first step is analysis of initial data – consumption analysis.

The new heat balance is comprised in the way to utilize the maximum heat gains providing building services with comfort conditions. Another one requirement for heat balance is appropriate number of members in equation, for convenient evaluation of energy saving measures. When heat balance is used for continual assessment the specific consumption (expressed in W/K) is more appropriate, because the indoor and outdoor climate information would be eliminated and only "pure" consumption analyzed. The energy generation is not considered, because the boundary of equation is only the building space.

The target of the analysis of energy consumption and implementation of energy saving measures is comfort conditions in the building. So the equation is rewritten by "bottom up" method, starting from final consumer to ensure comfort conditions in the building. In the left side of balance equation equality is heat, which is needed to ensure comfort conditions$\left(\sum \mathrm{A_i u_i} + \mathrm{c\rho} \sum \mathrm{V_j n_j}\right)$. And in the right side of equality the delivered heat is presented:

$$\sum A_{\mathrm{i}} u_{\mathrm{i}} + c\rho \sum V_{\mathrm{j}} n_{\mathrm{j}} = \sum H_{\mathrm{del}} + \eta_{\mathrm{T}}(H_{\mathrm{P}} + \eta_{\mathrm{E}} H_{\mathrm{E}} + H_{\mathrm{S}}) + \sum \eta_{\mathrm{R,k}} H_{\mathrm{R,k}} - \sum H_{\mathrm{L,k}} \quad (1)$$

Where H_{del} – specific resources consumption, W/K; $\left(\sum A_{\mathrm{i}} u_{\mathrm{i}} + c\rho \sum V_{\mathrm{j}} n_{\mathrm{j}}\right)$ – specific heat losses W/K; η_{T} – gains utilization factor according internal temperature; H_{P} –internal gains from inhabitants, W/K; η_{E} – utilization factor for gains from electric appliances; H_{E} – internal gains from electric appliances, W/K; H_{S} – gains from solar radiation, W/K; $\eta_{\mathrm{R,k}}$ – heat recovery efficiency factor; $H_{\mathrm{R,k}}$ – specific recovered heat from ventilation and domestic hot water systems, W/K; H_{L} – heat losses from building services systems, W/K.

The flow of delivered resources has two streams of energy (electricity and heat) and water. The electricity flow has two ways: one is electricity consumed by lighting, electrical and auxiliary appliances. The balance is based on heat flow, so in concept of heat, the energy (electricity) used but the heat which is not extracted is loss (H_{L}) in point of heat flow. The amount of energy from electrical appliances transformed to heat is heat gained from electrical appliances (H_{E}).

The described heat balance equation for distribution of heat according its origin lets to analyze and find the main points, where heat is consumed. This way of analysis is very visual how the utilization of gains and heat recovery possibilities can be used for more efficient energy use. Also this equation is applicable to energy analysis for continual improvement and is very handy when changes only part of energy consumption, and recalculations become easier, then only data about alternation needs to be recalculated.

Sustainable evaluation of EEM can be performed only estimating multicriteria. And multicriteria should cover and be integrated from different fields of science: energy, environment, economy, comfort and construction. The criteria tree with attributes and their optimization functions construct the general sustainability criteria, as it is shown in Fig. 1. The general sustainability criteria (GSC) tree consists of 5 criteria, which are expressed by attributes. All attributes have their optimization function, as it is shown in Fig. 1.

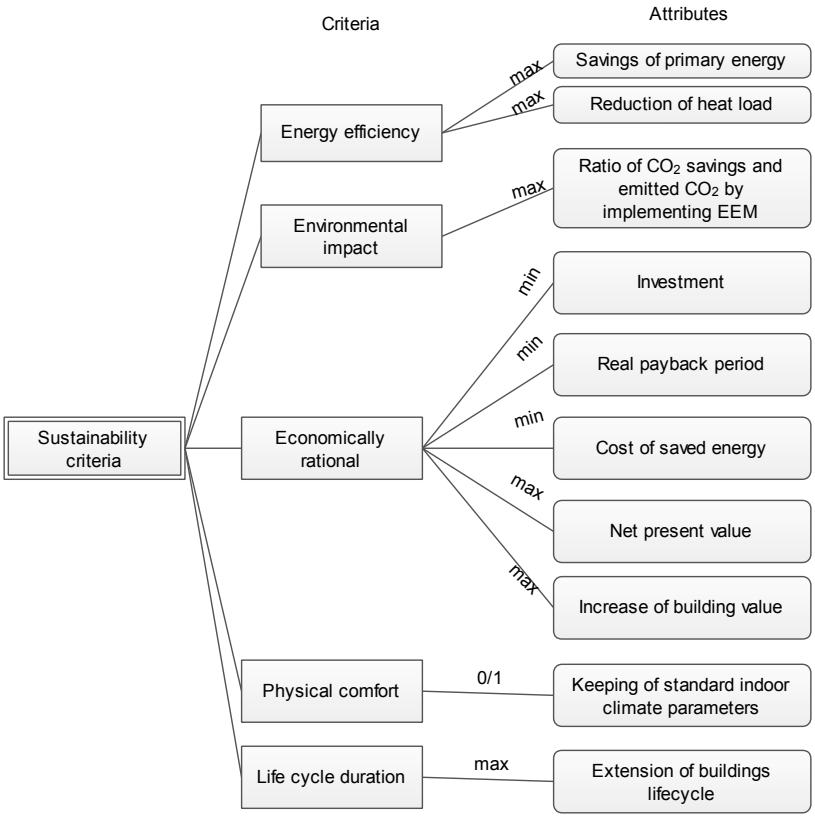

Fig. 1. Tree of sustainability criteria

The selection of criteria and assessment of their attributes is incomplete information for decision maker. Each attribute of the criteria has different units, different optimization functions. The normalization process by SAW method is

based by comparing attribute values of analyzed alternatives with the best result, and evaluation the difference from the best value.

Then separate EEM are evaluated, the next question for decision maker is how to form the packets of EEM. Sequential prioritization and distribution DT (DDT) is formed for distribution of EEM to the basic and additional EEM's. This method optimizes the formation of EEM packets.

The optimization sequence starts with finding the obligatory EEM, which should be implemented. The obligatory measures have to be defined by decision maker in the first stage, when building is analyzed. The obligatory measures are defined to accomplish the technological or comfort requirements of the building. Also obligatory measures can appear after modernization, and then characteristics of building are changed. All EEM should meet comfort criteria, so the EEM with comfort criteria should be met for all measures, otherwise is eliminated. The evaluation of EEM by general sustainability criteria (GSC) shows which EEM is the best, so it should be added in all packets. Second priority of the EEM is the best result of one of criterions (e.g. Energy saving, o economical rational), except comfort criterion. The comfort criterion is evaluated separately in second node of the tree, so is eliminated in the fourth node.

The formation of basic list lets to optimize the number of alternative packets and to optimize the decision making to find the best packet of EEM. So with 5 EEM only four packets can be formed instead of 31 if all packets are formed randomly from all EEMs. 10 EEM can form more than 1000 combinations, but distribution decision tree will optimize this number to 20 packets.

SMoBEPC is designed for public buildings. The purpose of the model is energy efficient building is sustainable point of view. It means that tightening of the building and "tightening" of energy bills should not pass the requirements for comfort.

In the first part of model algorithm the input about initial data is set and analyzed. The information about building characteristics is building architecture and construction and energy consumption (with the analogical climatic conditions). The architecture and construction are unvaried information except reconstructions cases. The energy consumption (heat and electricity) is varying every day, but has more or less cyclical period of one year.

Then initial building data is set, the actual energy consumption is recalculated to specific energy consumption and heat balance equation is formed. Then EEM are evaluated by GSC. Then separate EEM are evaluated, the packages of EEM are formed according distribution decision tree.

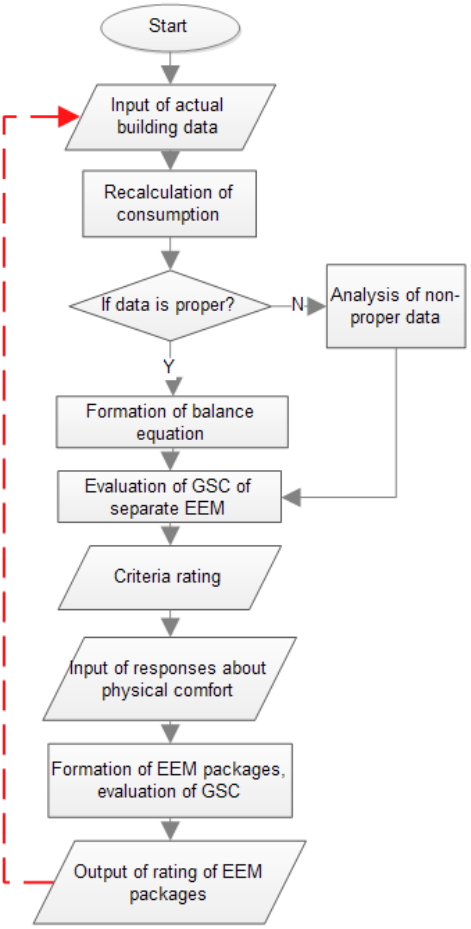

Fig. 2. The algorithm of sustainable management of building energy performance characteristics

The sequence of described sets is shown in Fig. 2, where the algorithm of sustainable management of building energy performance characteristics is presented. The discontinuous line shows the continuity of the process, there is no end in the algorithm, it is repeated periodically.

The SMoBEPC is computer assisted process for evaluation of energy consumption and it can evaluate opinion of each person in the building about comfort. Feedback of building occupants about physical comfort has to be

analyzed to separate the individual (personal) features, neutral comfort conditions and expected pleasant comfort conditions. The target of comfort conditions feedback system is to define the neutral comfort conditions and to seek for pleasant comfort conditions. The pleasant comfort conditions are not in the first target because pleasant conditions for different occupants (of different age, sex, metabolic rate and etc.) are different, but it can be as the secondary target.

The SMoBEPC is continual process which covers energy management system, monitoring and continual decision making tool. The last part of the algorithm is output of rated packages of EEM. This information is specialized for building administrators and managers as decision support tool for more energy efficient building use in sustainability point of view.

3. Analysis of results of implementation of model of sustainable management of building energy performance characteristics

In this chapter the case study of implementation of SMoBEPC is presented. The aim of case study is to show usage of the described model for the real buildings. The examination of model is prepared for two different public buildings. After initial data analysis, separate EEM there evaluated by general sustainability criteria. The list of EEM types is presented in the table 1.

Table 1. Description of energy efficiency measures (EEM)

Abbreviation of EEM type	Description of EEM
EEM1	Insulation of external walls
EEM2	Insulation of roof
EEM3	Installation of triple windows
EEM4	Installation of portal doors
EEM5	Insulation of ground floor
EEM6	Modernization of heat substation
EEM7	Modernization of heating system. Behavior for energy (heat) efficiency
EEM8	Modernization /implementation of mechanical ventilation system with recuperation
EEM9	Modernization of lighting system
EEM10	Behavior for energy (electricity) efficiency

The evaluation of each EEM attribute values are evaluated and normalized by each attribute optimization functions. Figures 3–4 provide charts principle as the larger area defined by the EEM curve, the higher the value of the GSC. It is also convenient to compare values for each criterion. The criterion value is farther away from the center, the greater its importance.

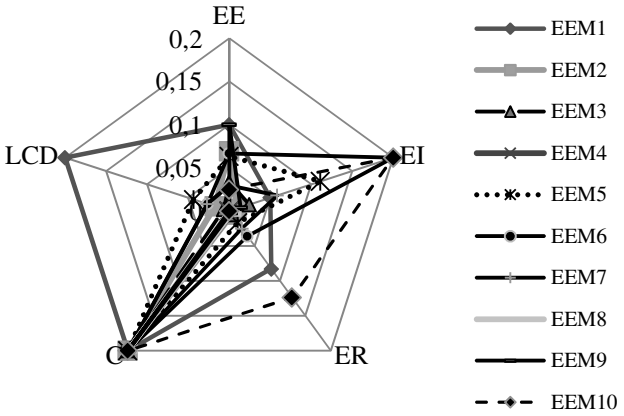

Fig. 3. Sustainability criteria of separate energy efficiency measures of building A

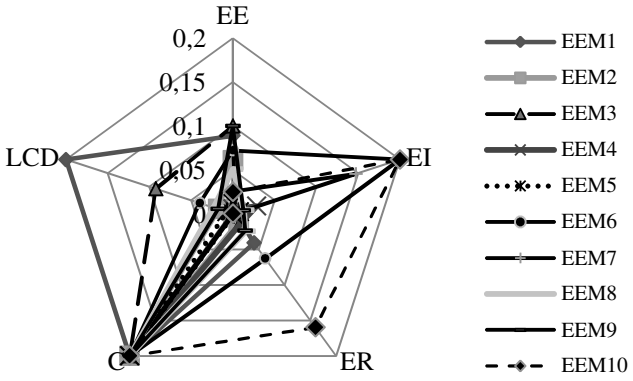

Fig. 4. Sustainability criteria of separate energy efficiency measures of building B

Sensitivity analysis for criteria weights was performed in four scenarios. The results show that the maximum GSC values change occurs in the environmental scenario. The changing political situation, and the emergence of

a greater focus on the environment, it would be reasonable to SMoBEPC give different weights for this criterion.

The packets formation where done by distribution decision tree. The best packages of both buildings differ, but the trend of complexity remains.

Proposed limited number of criteria for multicriteria analysis is characterized by clear structure, sequence as easily assessed reliability of received indicators. It enables to define the criteria values according the calculations of defined attributes. Sequential prioritization and distribution is formed under Generalization decision tree to optimize the number of EEM packages.

The example of two different cases shows, that evaluation of GSC express not only the economic benefit, but benefit for human's welfare and for environment as well - the sustainable and complex view to the building.

General conclusions

1. The review of energy audits, buildings assessment, monitoring and analysis of energy consumption showed that the and accuracy of method and level of detail depends on the aim of the analysis, which is usually only one (to assess the current energy consumption, influence of renovation measures, decisions making, building management tool). However, there is no one continuous building management tool that includes an analysis of the current energy consumption, sustainable assessment of measures, packet formation and the preparation of the decision-making.
2. The balance equation constructed on the basis of specific energy consumption inter alia show the uncertainty of energy consumption, rather than dependence on climatic conditions, so it is a suitable method to analyze human behavior and to evaluate the management of building characteristics.
3. Sustainable and comprehensive evaluation of energy efficiency measures should be carried out by complex criteria for assessing the energy efficiency, environmental impact, economic rationality, comfort and the building life cycle. The evaluation of energy efficiency measures by general sustainability criteria include building energy consumption, potential of environmental impact, the degree of depreciation of the building and the comfort conditions before the implementation of measures and after implementing them, and not just economic benefits.
4. The algorithm for grouping of measures based on sequential decision tree method, simplifies the decision-making process, the selection of

only those conditions that ensure comfort and have high values of sustainability criteria. The formation of basic packet reduces the number of possible alternatives to 2% of all mathematically possible alternatives.

5. The formation of energy efficiency packages showed that the complex installation of energy efficiency measures have more impact on the effective management of the building than the individual installation steps. Largest general sustainability criterion value of individual measures was 0.633 when general sustainability criterion values of grouped packets were 0.673 to 0.909 ranges, i.e. the minimum value of packets was higher than the maximum value of the individual measures.
6. The model for sustainable management of energy performance characteristics of the building is designed for continual building's energy performance monitoring, the improvement of the implementation of the principles of the building site management, and evaluating the potential of modernization measures by general sustainability criteria. It allows the selection of solutions for greater effectiveness.
7. Case study model of building sustainable management of energy performance characteristics of two different buildings has shown that the model is suitable for both buildings built before 1990 and belonging to the construction of a new building. This model is suitable for the various purpose public buildings as building maintenance and management tool. It can be used in the analysis of alternatives for the new designed buildings as well.

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PASTATO ENERGINIŲ SAVYBIŲ DARNAUS VALDYMO MODELIS

Problemos formulavimas – Šiuolaikinis ir modernus (*State of art*) pastatų ir jų atnaujinimo priemonių vertinimas jau suprantamas kaip nuolatinis procesas, o ne vienkartinis veiksmas. Nuolat atnaujinamų sprendimų priėmimo įrankių jau yra sukurta, bet jie dažniausiai remiasi tik ekonominiu vertinimo kriterijumi. Vis dėlto plinta supratimas apie pastatų atnaujinimo visapusę (ne tik ekonominę) naudą, bet stokojama bendresnės nuomonės, kokiais kriterijais remiantis tai turėtų būti vertinama. Dauguma mokslininkų sutaria, kad pastatų vertinimas turi būti atliekamas remiantis ne vienu kriterijumi, apimančiu įvairias su pastatu susijusias sritis: geresnes sąlygas patalpose, poveikio aplinkai mažinimą, pastato būklės pasikeitimą per jo gyvavimo ciklą. Darnaus vystymosi koncepcija dažnai minima, bet ją apibūdinančių kriterijų pastatams vertinti paieška tęsiasi tiek praktikoje, tiek moksle.

Šiame darbe nagrinėjami pastatų esamos būklės įvertinimo metodai, energijos taupymo priemonių darnaus vertinimo kriterijai, sprendimų priėmimo ir nuolatinio pastato valdymo įrankiai.

Mokslo problemos aktualumas – Naujos statybos pastatai Europoje sudaro tik mažą dalį visų pastatų. Esami pastatai yra pagrindinis energijos vartotojas pastatų sektoriuje, kurie sudaro apie 99% viso pastatų sektoriaus.

Griežtėjant ES reikalavimams naujai statomiems pastatams didėja atotrūkis tarp energijos sąnaudų esamuose ir naujai statomuose pastatuose. Esamų pastatų nuolatinis valdymas (priežiūra), jų energinio efektyvumo gerinimas darosi vis svarbesnis griežtėjant ES reikalavimams ir tobulėjant technologijoms.

Taigi, didėja komforto sąlygų gerinimo, informavimo apie energijos sąnaudas, jų sumažinimo priemonių paklausa. Kita vertus technologinių galimybių atsiradimas (PAVS sistemos, modeliavimo ir sprendimų priėmimo įrankiai) sudaro sąlygas ir poreikį nuolatiniam esamų pastatų energinių savybių valdymui. Kompiuterinėmis modeliavimo priemonėmis vis dažniau pastatai modeliuojami mažesniam energijos poreikiui pasiekti projektavimo metu, bet modeliavimo įrankiai jau naudojamo pastato energijos sąnaudų sumažinimo galimybėms įvertinti naudojami retai.

Nuolatinio energijos sąnaudų stebėjimo problemą dažniausiai sprendžia elektronikos ir automatikos srities mokslininkai. Jų atliekamos studijos nagrinėja valdiklių ir jutiklių veikimo patikimumą, klaidų šalinimą, duomenų apdorojimo ir saugojimo problemas. Šiose studijose energijos vartojimo efektyvumas dažniausiai suprantamas, kaip galimai sklandžiau veikiančios energetinės sistemos, bet neaptariamos jų pačių tobulinimo galimybės.

Taip pat kuriami nuolatinio valdymo įrankiai naudojami ir pastatų atnaujinimo galimybėms įvertinti, tačiau pasirenkami vieną ar tik kelias sritis įvertinantys kriterijai. Darnaus vystymosi koncepcija vis plačiau apima visas gyvenimo sritis ir turėtų būti taikoma pastatams vertinti juos atnaujinant, valdant, prižiūrint. Taigi ir šiuolaikinis pastato energijos poreikių valdymas turėtų būti organizuojamas remiantis ne tik ekonomine, bet ir socialine bei aplinkosaugine nauda, t. y. vertinant darnaus vystymosi koncepcijos principu.

Darbo tyrimų objektas – viešosios paskirties pastato energinės savybės, jų (savybių) pokyčių įtaka pastato nuolatiniam valdymui, pasikeitusių charakteristikų darnaus vertinimo kriterijai. Pastato energinių savybių nuolatinis valdymas čia suprantamas, kaip faktinės informacijos apie pastato būklę pagrindu formuojami sprendiniai veiksmingai prevencinei jo priežiūrai.

Darbo tikslas – parengti pastato energinių savybių valdymui skirtos nuolat veikiančios ekspertinės sistemos algoritmą, kuriuo darniai įvertinamos pastato atnaujinimo ir efektyvesnio energetinių išteklių vartojimo galimybės.

Darbo uždaviniai

Darbo tikslui pasiekti pasirinkta spręsti šiuos uždavinius:

1. Išanalizuoti esamas energinių auditų, pastatų vertinimo, monitoringo ir energijos sąnaudų analizės metodikas. Išanalizuoti pastato energijos poreikius, jų priklausomybę nuo įvairių faktorių, naudojamus energijos sąnaudų balansavimo algoritmus.
2. Sudaryti nuolatiniam pastato valdymui parankią balansavimo lygtį pastato energinėms savybėms nagrinėti.
3. Išanalizuoti pastatų energinį efektyvumą skatinančių priemonių vertinimo metodus. Apžvelgti mokslininkų naudojamus kriterijus energijos taupymo priemonėms vertinti, kriterijų sąsają su darnaus vystymosi koncepcijos komponentais. Sudaryti darnaus vertinimo kriterijų su juos išreiškiančiais atributais rinkinį energijos taupymo priemonėms įvertinti.
4. Sukurti darnaus vertinimo daugiakriterį metodą energinio efektyvumo didinimo priemonėms pastate vertinti, šioms priemonėms grupuoti į paketus.
5. Parengti pastato energinių savybių valdymo modelio algoritmą, kuriame būtų analizuojamos pastato energinės savybės, siūlomos diegti energijos taupymo priemonės, o jų įtaka pastatui ir aplinkai įvertinta darnumo kriterijais.

Tyrimų metodika. Pastato faktinės energijos sąnaudos analizuojamos perskaičiavus jas į savitąsias sąnaudas ir iš jų sudarant balanso lygtį. Balanso

lygtis sudaroma “bottom-up” (iš apačios) metodu pradedant nuo galutinio vartotojo, kai lygybės tikslas yra užtikrinti komfortines sąlygas pastate.

ETP priemonių vertinimas atliekamas daugiakriteriu vertinimu. Kriterijai normalizuojami SAW (*Simple Additive Weighting*) metodu. Nuosekli daugiakriterė ETP ir jų paketų vertinimo metodika sudaryta taikant sprendimų medžio metodą.

Mokslinis naujumas

Rengiant disertaciją buvo gauti šie energetikos ir termoinžinerijos mokslui nauji rezultatai:

1. Remiantis jau naudojamomis šilumos balanso lygtimis sudaryta balanso lygtis, skirta pastato energinių savybių darniam valdymui.
2. Sukurtas darnaus energijos taupymo priemonių vertinimo kriterijų medis bendrajam darnumo kriterijui įvertinti, kai gyvavimo ciklo trukmėje vertinama priemonių energijos taupymas, poveikis aplinkai, ekonominis racionalumas ir komfortas.
3. Sprendimų medžio metodu sukurtas algoritmas atnaujinimo priemonių paketų formavimui, kai priemonės atrenkamos į pagrindinį ir pagalbinį paketus.
4. Nuolatiniam pastato energinių savybių stebėjimui ir jų veiksmingumui gerinti sudarytas pastato energinių savybių darnaus valdymo modelis.

Praktinė vertė. Darbo rezultatai gali būti naudojami rengiant pastatų modernizavimo planus, siekiant efektyvesnio ir kokybiškesnio pastatų energijos poreikių valdymo darnumo koncepcijos principu pastatų priežiūros planuotojams, valdytojams ir modernizavimo galimybių vertintojams.

Ginamieji teiginiai

1. Savitųjų energijos sąnaudų analizė leidžia atsiriboti nuo klimatinių sąlygų įtakos. Nuolatiniam pastato valdymui, atskirų jo komponentų vertinimui būtina nagrinėti “bottom-up” metodu sudarytą energijos balanso lygtį, susidedančią iš tų komponentų savitųjų energijos sąnaudų.
2. Darnus ETP vertinimas turi apimti ne tik energijos taupymo, poveikio aplinkai ir ekonominę naudą, bet ir pasirinktą ar privalomą komforto lygį patalpose. Analizę pradedant “bottom-up” metodu nuo galutinio vartotojo numatomas reikalingas komforto lygis patalpose. Taip pat darnumas turi būti vertinimas pastato gyvavimo ciklo požiūriu.

3. Būtinų įgyvendinti priemonių nustatymas bei parengtas priemonių grupavimo būdas leidžia užtikrinti komfortines sąlygas pastate po renovacijos ir supaprastina sprendimų priėmimą.
4. Realių energijos ir kitų išteklių vartojimo duomenų stebėsenos ir analizės pagrindu nuolat veikianti derinių parinkimo ir sprendinių parengimo ekspertinė sistema padidina pastato priežiūros ir išteklių naudojimo darnumą, leidžia veiksmingiau naudoti pastatą, priimti savalaikius sprendimus dėl jo atnaujinimo.

Darbo apimtis. Darbą sudaro įvadas, 3 skyriai, išvados, literatūros sąrašas, publikacijų sąrašas. Bendra disertacijos apimtis – 84 puslapiai, 29 iliustracijos, ir 10 lentelių.

Pirmame disertacijos skyriuje nagrinėjami mokslininkų naudojami pastatų vertinimo pagal energijos sąnaudas metodai, energijos balanso lygtys pastatų analizei. Taip pat apžvelgiama pastatų modernizavimo vertinimo kriterijai, sprendimų priėmimo metodai, nuolatinio pastato stebėjimo ir analizės principai. Tiek inžinierių praktikų tarpe, tiek mokslinėje visuomenėje kyla klausimas kaip tiekiant kuo mažiau energijos suteikti pastatui kokybiškas energetines paslaugas. Atliekami tyrimai, studijos, kuriamos metodikos šiam klausimui atsakyti. Šiame skyriuje pateikiama atliktų tyrimų ir sukurtų metodų apžvalga, kurios pagrindu kuriamas pastato energinių savybių valdymo modelis.

Antrame disertacijos skyriuje pateikiamas darbe sukurtas pastato energinių savybių darnaus valdymo modelis ir jo veikimo algoritmas. Šis modelis skirtas nuolatiniam pastato valdymui ir stebėsenai bei atnaujinimo galimybių planavimui.

Trečiame skyriuje pateikti modelio taikymo rezultatai. Atvejo analizė atlikta dviem viešosios paskirties pastatams siekiant patikrinti 2 skyriuje pateikto pastato energinių savybių darnaus valdymo modelio pritaikomumą, jo poveikį pastato valdymo eigoje.

Bendrosios išvados

Suformuluotos šios mokslinės ir praktinės išvados:

1. Atlikta esamų energinių auditų, pastatų vertinimo, monitoringo ir energijos sąnaudų analizės apžvalga rodo, kad metodų tikslumas ir detalumas priklauso nuo analizės tikslo, kuris dažniausiai yra tik vienas (įvertinti esamas sąnaudas, atnaujinimo priemonių įtaką, pasirinkti sprendimų priėmimą, pastato valdymo įrankį). Tačiau nėra vieno nuolatiniam pastatų valdymui skirto įrankio, kuris apimtų esamų sąnaudų analizę, darnų priemonių vertinimą, paketų formavimą ir sprendimo parengimą jo priėmimui.

2. Balanso lygtis, sudaryta savitųjų energijos sąnaudų pagrindu, be kita ko, rodo ir sąnaudų neapibrėžtumą, o ne priklausymą nuo klimatinių sąlygų, todėl tinka žmogaus elgsenos įtakai energijos sąnaudoms analizuoti ir pastato energinių savybių valdymui įvertinti.
3. Darnus ir visapusiškas energijos taupymo priemonių vertinimas turėtų būti atliekamas remiantis kriterijų kompleksu, kuriuo vertinama energinis efektyvumas, poveikis aplinkai, ekonominis racionalumas, komfortas ir pastato gyvavimo ciklas. Energijos taupymo priemonių vertinimas bendruoju darnumo kriterijumi apima pastato energijos sąnaudas, poveikio aplinkai potencialą, pastato nusidėvėjimo laipsnį ir komforto sąlygas prieš priemonių diegimą ir jas įdiegus, o ne vien ekonominę naudą.
4. Sudarytas priemonių grupavimo algoritmas, paremtas nuosekliu sprendimų medžio metodu, supaprastina sprendimų priėmimo procedūrą, atrenkami tik tie, kurie užtikrina komforto sąlygas ir turi dideles darnumo kriterijų reikšmes. Pagrindinių priemonių paketo sudarymas sumažina galimų alternatyvų skaičių iki 2% visų matematiškai galimų alternatyvų.
5. Energijos taupymo priemonių paketų formavimas rodo, kad kompleksinis energijos taupymo priemonių diegimas turi daugiau įtakos pastato efektyviam valdymui nei pavienių priemonių diegimas. Pavienių priemonių didžiausia bendrojo darnumo kriterijaus reikšmė – 0,633, o sugrupuotų paketų bendrojo darnumo kriterijaus verčių intervalas 0,673–0,909, t. y. paketų bendrojo darnumo kriterijaus reikšmės yra didesnės nei atskirų priemonių bendrojo darnumo kriterijaus vertės.
6. Sukurtas pastato energinių savybių darnaus valdymo modelis, skirtas nuolatiniam pastato energinių savybių stebėjimui, jų gerinimui diegiant pastato energijos poreikių vadybos principus, ir vertinant galimas modernizavimo priemones bendruoju darnumo kriterijumi. Jis leidžia parinkti didesnio veiksmingumo sprendimus.
7. Dviejų skirtingų pastatų energinių savybių darnaus valdymo modelio atvejo analizė įrodė, kad modelis yra tinkamas tiek pastatams, pastatytiems iki 1990 m., tiek priskiriamiems prie naujos statybos pastatų. Taip pat modelis tinkamas įvairios paskirties viešiesiems pastatams, kaip pastatų priežiūros ir valdymo įrankis. Jis gali būti naudojamas analizuojant naujai projektuojamų pastatų alternatyvas.

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MODEL OF SUSTAINABLE MANAGEMENT
OF BUILDING ENERGY PERFORMANCE CHARACTERISTICS

Summary of Doctoral Dissertation
Technological Sciences, Energetics and power engineering (06T)

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