DOI: http://dx.doi.org/10.21686/2410-7395-2024-1-177-194

ОЦЕНКА РЕАЛИЗАЦИИ МЕЖОТРАСЛЕВЫХ ПОКАЗАТЕЛЕЙ ЭФФЕКТИВНОСТИ ПРОГРАММ ЭНЕРГОСБЕРЕЖЕНИЯ В ЖИЗНЕННОМ ЦИКЛЕ ЗДАНИЙ

А. С. Будаков
Российский университет дружбы народов имени Патриса Лумумбы,
Москва, Россия

Статья посвящена исследованию мировой практики возможности энергосбережения зданий. Актуальность статьи состоит в том, что роль эффективности программ энергосбережения в настоящее время возрастает. Новизна исследования заключается в разработке методологии и новых подходов к анализу энергосбережения. Автор предлагает межотраслевые показатели стратегического управления программами энергосбережения. Они могут предоставить анализ широкого спектра полезной информации для подтверждения затрат на инвестиции, эксплуатацию и эффективность проекта. В качестве основы исследования в статье используется информационное моделирование зданий. На основе анализа научной литературы автором разработаны межотраслевые показатели стратегического управления программами энергосбережения. Приведен расчет энергосбережения с учетом таких новых показателей, как показатели восстановительной стоимости, показатели потерь электроэнергии, воздействия на окружающую среду, показатели надежности. Предложена методология оценки воздействия решений по управлению энергопотреблением и использования ключевых показателей эффективности. Методология состоит из подготовительного этапа и двухэтапной оценки. Она может быть использована для количественной оценки конкретных аспектов или целей проекта, таких как экономическая осуществимость, воздействие на окружающую среду, надежность и качество электроэнергии. В исследовании автором использовались общенаучные методы
Ключевые слова: энергозатраты, информационное моделирование зданий, мировая практика.

ASSESSMENT OF THE IMPLEMENTATION OF CROSS-INDUSTRY PERFORMANCE INDICATORS OF ENERGY SAVING PROGRAMS IN THE LIFE CYCLE OF BUILDINGS

Alexey S. Budakov
Peoples' Friendship University of Russia named after Patrice Lumumba,
Moscow, Russia

This article is devoted to the study of the possibility of energy saving of buildings. The relevance of the article lies in the fact that the role of efficiency of energy saving programs is currently growing. The novelty of the research lies in the development of methodology

and new approaches for the analysis of energy saving. The author suggests cross-industry indicators of strategic management of energy saving programs. They can provide analysis of a wide range of useful information to confirm the costs of investment, operation and efficiency of a project. Information modeling of buildings is used as the basis of the research in the article. Based on the analysis of scientific literature, the author has developed cross-sectoral indicators of strategic management of energy saving programs. The author proposes a calculation of energy saving taking into account such new indicators as indicators in terms of replacement cost, indicators of power losses, environmental impact, reliability indicators. A methodology for assessing the impact of energy management solutions and the use of key performance indicators is proposed. The methodology consists of a preparatory stage and a two-stage assessment. It can be used to quantify specific aspects or objectives of a project, such as economic feasibility, environmental impact, reliability and quality of electricity. In the study, the author used general scientific methods of systematization and classification of data, methods of statistical processing and generalization, logical, comparative and system analysis, as well as mathematical methods.
Keywords: energy costs, energy conservation, energy efficiency, life cycle of buildings

Introduction

Energy conservation and energy efficiency are playing an increasingly important role at the macro and micro levels. These indicators have an impact on the short-term economic dynamicsof many countries, especially those that do not have their own energy resources. Today, the energy consumption of households and enterprises greatly affects the majority of economic indicators of all countries. In this regard, the study of the possibility of improving the energy efficiency of buildings and the search for new methods of increasing it in construction are of growing practical importance.

As noted in work of T. V. Ancharova, the continuous increase in the cost of energy resources is forcing energy companies and producers of goods and services to increase efficiency in the use of these resources and to optimize the cost of their payment. To achieve this, first of all, it is necessary to organize a complete and accurate accounting of all energy resource instruments. The restructuring of the Russian RAO UES, which has begun, the organization of the wholesale electricity market, the reform of housing and communal services, which is gaining momentum, and the systematic elimination of "cross-subsidies" for domestic consumers have significantly increased the interest of electricity producers and consumers in improving the organization of accounting in general and automated accounting systems, control and management of electricity consumption (askue) in particular [2].

As B. I. Kudrin noted in his scientific and educational manual [9], usually, the electricity metering system is meters that directly capture data on electricity consumption, as well as data transmission elements and their further processing on the main energy industry computer. The disadvantage of such a system is that there are many manufacturers of meters, Data Transmission devices, programmers and software options on the market that try to "combine" integrators. Sometimes it happens that protocols are not compatible and controllers require separate Firmware, etc.

All this takes time and, more importantly, resources that the customer has to pay for. Therefore, many companies, when it becomes the issue of modernizing the electricity metering system in an enterprise, study this problem with great fear, pose large budgets and implementation time, because they will be forced to get bogged down in the long and complex process of installing the technical metering system

Electricity metering can open up new opportunities to improve business efficiency. In this case, state-of-the-art solutions in this field, integrated with advanced software, can not only provide accurate data for each energy consumption unit (from a single machine to entire production lines and workshops), but also warn of potential equipment failures and thus predict possible breakdowns and breakdowns.

This, and more, is what distinguishes today's electricity metering systems from traditional ones, as we will try to understand in this article.

Typically, electricity metering systems are represented by meters that directly take data on electricity consumption, as well as the data transmission elements and their further processing by the main computer. The disadvantage of such a system is that there are many manufacturers of meters, data transmission devices, programmers and software options on the market, which the integrator companies try to "combine". Sometimes protocols are incompatible and controllers require separate firmware, etc. All of this takes time and, most importantly, resources for which the customer has to pay. This is why many companies, when the question of modernization of electrical metering systems in a company becomes, much fear the study of this issue, imposing large budgets and implementation conditions, because they are forced to get stuck in a long and complicated process of installation of technical metering systems.

The main directions of the research can be expressed as follows:

1. Reduction of electricity costs through automatic monitoring of the plant operation and proper planning of peak load. Benefits are achieved through the rational use and reduction of unproductive electricity losses.
2. Reduction of current and higher repair costs by setting up typical alarms during equipment operation and fault prediction.
3. Increase of employees' productivity due to remote control of equipment operation rules (equipment on/off modes, equipment shutdown).
4. Identification of "invisible" losses and unproductive energy consumption through full internal power metering and data analysis with built-in automatic weekly / monthly / quarterly reports.
5. Optimization of energy consumption through optimal management strategies.

The study of energy conservation management issues is mostly related to the study of alternative energy sources, the description of technological capabilities, their impact on potential economic efficiency.

Russian and foreign literature pays considerable attention to the organization of energy conservation management and energy efficiency improvement. A significant proportion of such issues are related to the study of local energy management tasks and the study of institutional principles, while organizational and technological barriers remain outside the scientific focus.

The development of a methodology aimed at studying energy efficiency with new indicators that more accurately reflect the level of energy costs of buildings could provide a more gradual and clearer accounting of these costs. To control energy consumption, it is important to be able to use managed online tools for evaluating key performance indicators. Such tools continuously provide users with information about the impact of energy management measures.

Methods

Methods of studying information modeling in construction and the formation of parameters for assessing the effectiveness of energy-saving measures

For the past 20 years, life cycle assessment has been widely used as a sustainable methodology that has the potential to quantify and reduce the environmental impact and energy consumption of building systems [13; 16].

In structural engineering, in addition to LCA (Building Life Cycle Analysis), other energy-efficient strategies often include reducing the use of materials and manufacturing energy, as well as increasing the reuse rate of structural systems.

Since there is no single approach that can solve all the problems of sustainable structural systems, it is crucial to understand the flow of interactions between materials, components and processes within the life cycle of a building in order to successfully cope with emissions into the environment at the national and global levels.

Some of the challenges that civil engineers still face when implementing sustainable structural systems are:

1) the cost of reduction (economic level);
2) convincing customers of potential benefits (industrial level);
3) informing interested parties about available constructive alternatives (level of education);
4) ensuring that sustainable solutions do not degrade structural characteristics (level of efficiency).

In addition, the limited use of sustainable environmental approaches in building structures is often due to the lack of reliable and user-friendly computational tools.

Building Information Modeling (BIM) is defined as a set of interacting policies, processes, and technologies that create a methodology for managing basic building design data in a digital format throughout a building's lifecycle.

BIM is seen as a consolidated model that can often be used to store and communicate geometric, spatial relationships, geographic information, the number and properties of various building components, cost estimates, inventories, and project schedules [4].

In construction projects, where multiple stakeholders are involved in decision-making procedures, BIM can be implemented to improve information exchange and collaboration in the design and construction phases.

The use of BIM could revolutionize the way environmental impact and energy consumption models are integrated into building systems [8; 14].

BIM is widely used as a platform that enhances the capabilities of the project team to coordinate construction documentation, monitor construction work and manage the various stages of building operation in a comprehensive and systematic manner.

Research activities have begun to develop new BIM applications that solve a number of problems related to sustainability:

– environmental impact assessment;
– waste management;
– environmental design guidance;
– a government strategy to reduce carbon emissions in both current and future housing stock.

However, further research is needed to integrate BIM with sustainable and green building strategies to maximize environmental and energy benefits at different stages of a building's life cycle [18; 19].

In this collaborative decision-making process, civil engineers can use applications integrated with BIM to go beyond material selection and focus on design decisions that holistically optimize the material performance of buildings.

In structural systems, the advantages as well as limitations of BIM integration have been described by Solnosky, while Nawari et al. suggested that integrated structural analysis of BIM will allow engineering students and practitioners to develop a more nuanced understanding of various structural concepts [11; 17].

The next generation of BIM-based structural modeling platforms will include design and modeling (code validation and feedback), design analysis and modeling (simulations), component detailing/modeling (assemblyability), manufacturing modeling, and construction application modeling (coordination). In addition, the integrated structural design and construction processes within BIM can be divided into three phases, which include:

1) conceptual design;
2) system design;

3) component design.

Traditionally, the main reasons for the lack of built-in and sustainable decision-making practices in the construction of structural systems have been considered to be the inadequacy or inefficiency of policy requirements related to sustainable structural performance, and confusion among many practitioners regarding effective energy-efficient structural systems.

In practice, the involvement of civil engineers in the selection of sustainable development and energy saving strategies is usually neglected. Other limitations that limit the application of sustainable methodologies in structural design practices include:

1) the additional design and analysis time required to conduct detailed material- and system-level optimization studies;

2) uncertainty of the relationship between structural systems and the production energy of materials;

3) lack of connection between the embodied energy of materials with structural characteristics;

4) uncertainty and resistance regarding the overall capabilities of the LCA;

5) lack of systematic reuse mechanisms for accurate modeling and verification of the universality of building structural systems.

The authors see the current development of BIM as an opportunity for civil engineers to radically change existing procedures for the design and supply of energy-efficient structures by expanding the design field into the field of sustainable performance and creating a space of synergistic solutions that operates within the framework of the overall BIM policy.

Growing concerns about climate-resilient buildings are expected to reinforce demands for new decision-making paradigms in building structures that complement traditional engineering performance indicators (cost, safety, and construction capability) with sustainable components (energy use, resource depletion, emissions, and waste).

Sustainable Energy Assessments of Building Structures

LCA approaches have been used in buildings to inform sustainable and energy-efficient solutions by examining their environmental impacts. An LCA is an analytical assessment procedure that quantifies the potential environmental impact of products, processes or systems over their lifetime and covers the stages from extraction and production of raw materials to operation and end of life.

The LCA methodology consists of four distinct phases: Purpose and Scope Definition, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA), and Interpretation.

The international standard ISO 14040 defines LCA as a method of assessing the environmental aspects and potential impacts associated with a product by[1]:

– compilation of a register of relevant inputs and outputs of the product system;

– assessment of potential environmental impact;

– interpretation of the results of the stages of inventory analysis and impact assessment.

Stages of the building life cycle

Energy efficiency measures in buildings focus on environmental impacts in the following phases:

1) implementation phase;
2) operation phase;
3) end-of-life phase.

The operational stage of an LCA is associated with energy emissions during the operation phase of a building and typically covers a significant portion of its total emissions over the life cycle.

Operational impacts accumulate over time and can be significantly affected by the nature of occupants' energy use and the efficiency of the systems [7].

Finally, the end-of-life stage of the LCA includes impacts related to demolition, landfilling, and recycling or reuse processes.

Total energy emissions over the life cycle of a building are the sum of realized emissions, operational emissions, and end-of-life emissions.

Energy-efficient structural systems

LCA has great potential to make energy-efficient decisions, especially when applied in the early stages of the design process, especially when selecting materials and systems, when evaluating alternative design options, when developing a construction program, etc.

LCA applications can be divided into two main categories depending on whether the use/operation phase is included in the study. Ortiz et al. found that 60% of the studies they studied used LCA only to evaluate building components and materials [12].

On the other hand, only 40% of cases involve the analysis of the entire life cycle. The application of LCA can be organized at two consecutive levels depending on whether the structural system is studied in isolation (system level) or as part of the evaluation of the entire building (building level).

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[1] ISO 14040 "International Standard ISO 14040 in Environmental Management – Life Cycle Assessment – Principles and Framework / International Organization for Standardization. – Geneva, Switzerland, 2006.

Despite the fact that Dixit et al. and Miller & Doh's have carried out extensive work in this area, standardized systems for the environmental assessment of building structures, taking into account the following features [5; 10]:

1) discrepancies between embodied and operational energy;
2) limited consideration of energy efficiency strategies by construction professionals, still underdeveloped.

Recent research approaches focus on improving the quality of LCA data and reducing uncertainties in the retrieval of inventory information. LCA input-output (IO-LCA) methods are suitable for the analysis of basic building materials using data from a nationwide perspective using national input-output tables (IOTs). However, IO-LCA is not suitable for individual buildings due to the complexity associated with construction projects, where hybrid LCA methods are more appropriate. Hybrid methods combine I/O models with more robust and object-specific data. When evidence is not available, other new LCA approaches related to the LCI reliable inventory specification include Bayesian theoryand the agent-based model (ABM).

The Data Quality Indicator (DQI) involves Monte Carlo sensitivity analysis, path exchange, system dynamics, and semantic approaches. Overall, future developments in this area will require integrated interdisciplinary models of environmental and energy lifecycle analysis to support new policies, harmonize with existing assessment approaches, consolidate decision-making processes, and account for advances in computing and information technology such as data mining, artificial intelligence, and optimization.

The "Results" section will describe the basic mechanisms of the mathematical-economic analysis of resource estimation and how to estimate losses of energy resources, active and reactive capacities, and analyze the average frequency of interruptions in energy systems, economic and non-economic related costs.

The combined application of the developed indicators to assess the relevant indicators will ensure the implementation of cross-industry indicators related to energy conservation and energy efficiency improvement.

The state standards of the Russian Federation were also analyzed in correspondence with the federal law of the Russian Federation on energy conservation and energy efficiency improvement.

Discussion

Cross-industry indicators of strategic management of energy saving programs can provide a wide range of useful information to confirm the costs of investment, operation and effectiveness of a particular solution. Cross-sectoral indicators of strategic management of energy saving programs in the context of strategic planning documents can be used to quantify specific aspects or objectives of the project, such as economic feasibility, environmental impact, reliability and quality of electricity.

The objective of economic viability can be determined by different indicators depending on the area of the microgrid being assessed.

Current features of decision-making in the design of buildings

Economic decision-making in building design was focused on energy measures related to the operational phase, as the main driving force was the growing political agenda related to the use of energy in buildings.

In the past, research has analyzed the effects of different building materials on energy performance without taking into account the influence of other phases of the building's life cycle.

In addition, there is no policy regulating the number of non-operational impacts of a building implemented. However, moving to stricter energy policies and zero-energy buildings (ZEBs), improvements to the embodied energy phase are expected to become more and more significant as operational energy declines. Significant differences arise between the distribution of calculated estimates of realized and operational energy for different building structures.

Results

Results of the study of information modeling and development of indicatorsof the effectiveness of energy saving programs to the Russian industry

For this assessment, indicators such as the capital costs of implementing a particular solution, the cost of replacing its components, the cost of maintenance, the cost of operation/generation and the cost of power loss can be used.

Indicators related to capital expenditures should reflect the economic feasibility of the components of the solution, allowing you to choose the implementation of a microgrid with the lowest start-up investment and capital expenditures.

The corresponding indicators can be determined by the following formula:

$$EXP_{cap} = CCAP_{var} \cdot K_{recover}\left(C_{\%}, SL_{term}\right) = CCAP_{var} \cdot \frac{C_{\%} \cdot \left(1 + C_{\%}\right)^{SL_{term}}}{\left(1 + C_{\%}\right)^{SL_{term}} - 1},$$

where $CCAP_{var}$ – the initial capital value of the components of the solution;

SL_{term} – service life of the decision-makers, month/year;

$K_{recover}$ – Capital recovery ratio (i. e. the coefficient representing the value of the annuity);

$C_{\%}$ – Interest rate, which is related to the nominal interest rate and the annual inflation rate.

Replacement cost figures represent the cost of all replacement costs incurred over the lifetime of a component of the solution.

$$C_{subst.} = C_{replace} \cdot K_{cash\ flow\ val.}\left(C_{\%},\ SL_{term}\right) = C_{replace} \cdot \frac{C_{\%}}{\left(1 \cdot C_{\%}\right)^{SL_{term}} - 1},$$

where $C_{replace}$ – the cost of the components of the solution (for example, a battery or a meter), million units;

SL_{term} – service life of the decision-makers, month/year;

$K_{cash\ flow\ val.}$ – a ratio that reflects the future value of a series of cash flows of equal period;

$C_{\%}$ – interest rate.

The cost of maintaining the system can be fixed as a constant value of millions of units in each specific period of time (i. e. monthly or annually depending on the duration of the project).

The costs of generating energy in a distributed generation source (RDI) are related to the fuel consumption and fuel price for IGIs that consume coal or gas (e. g. microgas turbines and diesel engines) and can be determined by the following formula:

$$C_{Subst.} = \sum_{t=1}^{T} \sum_{i=1}^{N} \left[K_{fuel}(i,t) \cdot POW_{sdg}(i,t) \cdot K_{0(i,t)} \cdot POW_{sdg}(i,t)\right],$$

where $K_{fuel}(i,t)$ – fuel coefficient of the i-th source of distributed generation, million units/kWh;

$K_{0(i,t)}$ – coefficient of operation of the i-th IRG, million units/kWh;

$POW_{sdg}(i,t)$ – the power generated (in kW) by the i-th source of distributed generation at time t.

Indicators of power loss

Includes both active and reactive power losses. Active power losses take into account AC and DC components, namely AC transformers, AC distribution lines, DC converters, and so on. Reactive power losses apply only to AC components. Active and reactive power values can be determined by the following formulas:

$$\Delta POW_{active} = \Delta POW_{alt.\ curr-losses} + \Delta POW_{direc.\ curr-losses} = \sum_{l=1}^{L} I_l^2 R,$$

$$\Delta POW_{reactive} = \sum_{l=1}^{L} I^2 X,$$

where I – is the amperage of the current in the circuit section;

R – active resistance of the circuit section;

X – the reactance.

Environmental impact

To achieve the goal related to environmental impact, indicators are needed that measure greenhouse gas emissions produced by sources of distributed generation.

The following formula can be used to estimate CO2 emissions:

$$ES_{CO_2} = \sum_{t=1}^{T} \sum_{i=1}^{N} \left[K_{sdg_i} \cdot COST_{CO_2} \cdot POW_{sdg(i,t)} \right],$$

where K_{sdg_i} – mission factor of the i-th source of distributed generation, kg/kWh;

$COST_{CO_2}$ – he cost of greenhouse gas emissions, million units/kg.

The following formula can be used to estimate CO_2 emissions in buildings from the perspective of external suppliers (where external suppliers are also taken into account, e.g. in buildings):

$$ES2_{CO_2} = \sum_{t=1}^{T} \left(\sum_{i=1}^{N} POW_{sdg\ (i,t)} \cdot K_i + \sum_{s=1}^{S} POW_{exter.\ supp\ (s,t)} \cdot K_s \right),$$

where $POW_{exter.\ supp\ (s,t)}$ – ower received from an external supplier s, kW;

K_s – CO_2 emission factor by distributed generation sources and external suppliers, kg CO_2/kWh.

Reliability indicators

Can be divided into load point reliability and system reliability. Load point indicators cover the following three aspects:

– frequency of load interruptions (cases per year);
– average duration of load interruptions (periods per year);
– average annual duration of load interruptions (hours per year).

On the other hand, the list of generally accepted system indexes includes:

1. The index of the average frequency of interrupts in the system, determined by the formula:

$$I_{Interrupt\,freq.} = \frac{\sum \lambda_i \cdot Consum_i}{\sum Consum_i}.$$

2. The index of the average duration of interruptions in the system, determined by the formula:

$$I_{Interrupt} = \frac{\sum AV.\,duratiom_i \cdot Consum_i}{\sum Consum_i}.$$

3. The service availability index, defined by the formula:

$$I_{\substack{Availability\\services}} = \frac{H_{estimate} \cdot \sum Consum_i - \sum (AV.\,duration_i \cdot Consum_i)}{H_{estimate} \cdot \sum Consum_i},$$

where $Consum_i$ – number of consumers at load point *i;*

λ_i – Failure rate at load point *i;*

$AV.duration_i$ – the average duration of the load interruption at load point *i;*

$H_{estimate}$ – The number of hours considered for evaluation.

The quality of electricity can be measured by three indicators, namely: the quality of the voltage, the power supplied from the source of distributed generation, and the overall harmonic distortion.

a) The voltage indicator is related to the voltage limitations in the electrical networks.

The quality of the voltage can be determined by the following formula:

$$V_{quality}\,\% = \frac{\sum_{t=1}^{T} T_q(t)}{T}.$$

where $\sum T_q\%$ is the accumulated time during which the voltage meets the requirements.

b) Electricity supplied from distributed energy resources: this indicator reflects the total production of electricity, i.e. sources of distributed generation and energy storage systems can be determined by the following formula:

$$Production_{SDF_{(t)}} = \sum_{t}^{T} \sum_{u=1}^{N} Production_{DER_{(u,t)}} .$$

c) Total harmonic distortion: Harmonic distortion depends on both the load level and the state of the system. Harmonic distortions can be determined by the following formulas:

$$V_{harm\ distortion} = \frac{\sqrt{\sum_{n-2}^{\infty} V_n^2}}{V_1}$$

$$I_{harm.distortion} = \frac{\sqrt{\sum_{n-2}^{\infty} I_n^2}}{I_1} ,$$

where V_n and I_n are the voltage and current at different times respectively.

The implementation of operational monitoring of the implementation of the energy saving program can be carried out according to the algorithm presented in Figure. A special role is played by basic data of intellectual monitoring based on historical data, including information on baseline performance indicators and an initial analysis of the costs incurred.

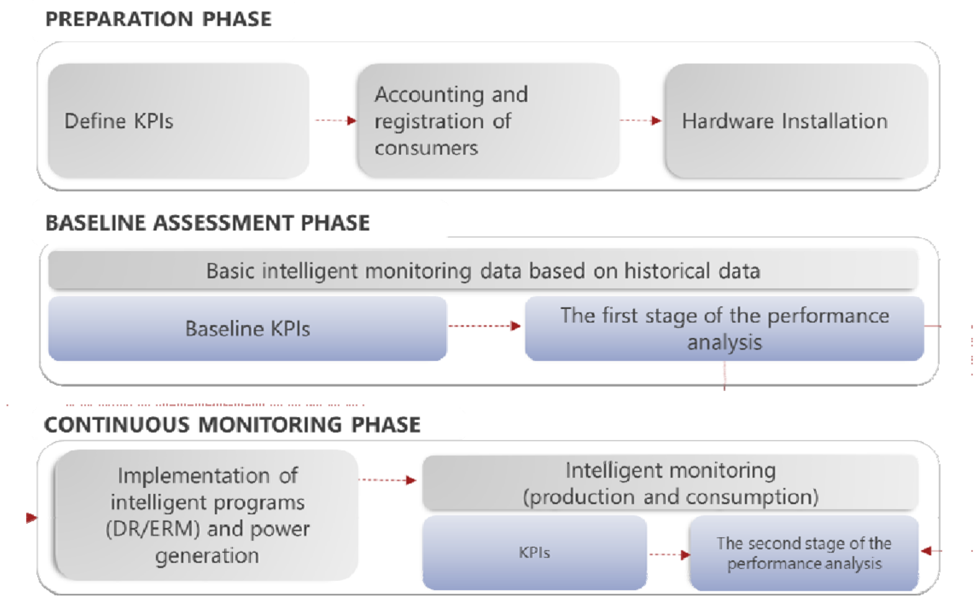

Figure. The algorithm of energy saving program implementation

KPIs and methodology

Figure provides a methodology for assessing the impact of energy management and KPI management solutions. The methodology consists of a preparatory phase and a two-stage evaluation.

In the preparatory phase, the initial steps necessary to evaluate the proposed methodology are performed. Phase zero involves selecting KPIs to be evaluated, including customers in programs, and installing equipment.

Then, in the first phase of the assessment, a baseline is constructed based on the monitoring of the selected buildings and a cost-benefit analysis is carried out.

In the second stage, intelligent programs are applied and new data is collected to determine the impact of the analyzed programs. The second stage can be applied periodically to improve the operation of the system and obtain benefits for both consumers and operators.

Baseline KPI

The baseline is built using information obtained during intelligent monitoring.

These measurements are used to calculate the average annual consumption pattern and monetary costs resulting from the application of different types of tariffs to different residential buildings and buildings of the energy community.

The total base load from the various buildings is calculated as:

$$Load_{Cumulate.} = \sum_{nb=1}^{B} \sum_{d=1}^{D} \sum_{t=1}^{T} Load._{(b,d,t)},$$

Where $Load._{(b,d,t)}$ – The load of the building is "b", on day "d" and time "t".

Thus, $Load_{cumulate}$ corresponds to the total load of a certain number of houses "B", for the period "D" days, each day has "T" measurements.

Following the same logic and having available prices for different tariffs $Tariff_{(t,type)}$, the resulting base annual cost for different types of tariffs is determined as follows

$$Bas.\ cost_{Year,\ type} = \sum_{nb=1}^{B} \sum_{d=1}^{D} \sum_{t=1}^{T} Load._{(b,d,t)} \cdot Tariff_{(t,type)}.$$

Tariff determination and calculation of annual costs and aggregated loads are carried out using available controlled measurements.

Impact of photovoltaic generation

Once the baseline has been identified, the current information resulting from the established program can be used to conduct a cost-benefit analysis. In particular, in the example discussed in this article, it is necessary to assess the impact of the sharing of photovoltaic generation in the energy community. To do this, the power of photovoltaic generation can be calculated as:

$$POW_{feg} = \sum_{d=1}^{D} \sum_{t=1}^{T} POW_{fe\ (d,t,b_n)},$$

where $POW_{fe\ (d,t,b_n)}$ is the power generated by the photovoltaic installation installed in the building bn, on day d, and at time *t*.

Assuming that photovoltaic installations are installed in specific buildings, the annual cost can be recalculated taking into account the self-consumption of photovoltaic energy as follows:

$$Cost_{year} = \sum_{d=1}^{D} \sum_{t=1}^{T} \left[(Load_{(d;t;b_n)} - POW_{fe\ (d;t;b_n)}) \cdot Tariff_{(t,type)} \right],$$

where $Cost_{year}$ is the annual cost for the building b_n after the use of self-consumption of photovoltaic generation for several types of tariffs.

With this second calculation, it is possible to obtain an estimate of the savings by comparing the baseline value and the effect of self-consumption of photovoltaic generation:

$$\%\ Saving = \left[\left(COST_{bas} - COST_{fe} \right) / COST_{bas} \right] \cdot 100\cdot$$

Robustness

This paper presented a methodology for analyzing KPIs to assess the impact of energy management solutions. A methodology based on the use of KPIs was proposed as a basis for establishing a baseline and assessing the impact of different KPIs. The methodology allows the use of KPIs to abstract the information obtained during the measurement of energy consumption into quantitative data with a natural interpretation.

On the implemented example, it was possible to see how the KPI of electricity bills (and savings) for 1 year will change as a result of the installation of photovoltaic generation in public buildings and, ideally, changes in the energy tariff in order to better choose the one that better corresponds to the profile of photovoltaic generation. Using the proposed simple methodology, it was possible to estimate the KPIs of electricity bills with different tariffs and photovoltaic generation over time, whereas in previous studies the results were compared only at the end of the day or at the end of the month or year.

The results showed that savings of up to 11.27% can be achieved through the use and sharing of photovoltaic generation. Moreover, the application of different tariffs with the same consumption patterns can be reflected in annual costs and savings. The application presented in this example is fairly simple to illustrate.

Thedeveloped methodology can be applied in various contexts to assess the value of various energy management projects managed by the online assessment tool KPI, which dynamically provides users with information on the impact of energy management measures.

Conclusion

Buildings have a huge potential for energy efficiency. To achieve this huge potential, some regulations and initiatives should be taken to improve the efficiency of buildings. Energy consumption in buildings occurs at every stage of the building's life cycle. However, an important stage is the use and maintenance of buildings, where energy is consumed the most as part of the life cycle. Throughout the life cycle of the building, the highest energy consumption occurs during the use phase. This is because this period is much longer compared to other phases and it is during this phase that the level of comfort necessary for one's health and work efficiency must be ensured. Therefore, energy-efficient construction of buildings, especially in the use phase, should be taken into account.

In order to reduce energy consumption during the use of the building, renewable energy sources should be preferred instead of fossil. Attention should be paid to renewable energy sources. Particular attention should be paid to the use of active and passive systems. Energy modeling programs should be used in the design of buildings.

As the function, system and location of the building vary from building to building, so do the solutions that ensure energy efficiency. Therefore, a conscious approach needs to be developed to find the right solution at the architectural design stage by providing the necessary data.

The end product should aim to be more efficient, in other words, to use fewer resources over a longer period of time to perform the same action.

The constant rise in the cost of energy resources and the significant increase in their consumption in recent years make us think seriously about stricter control over their use, as well as require the introduction of effective of energy saving, as well as the development of an energy-saving policy and measures to reduce energy consumption.

The use of automated control systems in any sphere of life and activity makes it possible to control energy resources consumption accurately and quickly, thus increasing reliability, optimizing energy costs and making life more comfort and convenience.

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Сведения об авторе

Алексей Сергеевич Будаков
Аспирант кафедры политической экономии имени В. Ф.Станиса. РУДН.
Адрес: ФГАОУ ВО «Российский университет дружбы народов имени Патриса Лумумбы», 117198, Москва, ул. Миклухо-Маклая, д. 6.
E-mail: budakovalexey@gmail.com

Information about the author

Alexey S. Budakov
Post-Graduate Student of the Department of Political Economy named after V. F. Stanis of RUDN University.
Address: Peoples' Friendship University of Russia named after Patrice Lumumba (RUDN University), 6 Miklukho-Maklaya Street, Moscow, 117198, Russian Federation.
E-mail: budakovalexey@gmail.com