

OPTIMIZATION OF ENERGY CONSUMPTION IN BUILDINGS
USING MANAGEMENT SYSTEMS, DEVELOPMENT OF ENERGY
MANAGEMENT STRATEGIES TO IMPROVE EFFICIENCY

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Abstract: *The article examines approaches to optimizing building energy consumption using Energy Management Systems (EMS). An analysis of the current state of building energy consumption in the Republic of Uzbekistan is provided, along with management strategies including the integration of renewable energy sources. The effectiveness of the proposed solutions, which ensure a reduction in energy costs by 18–25% and a decrease in carbon footprint, is demonstrated. The necessity of introducing national standards and government support for EMS scaling is substantiated.*

Keywords: *energy consumption optimization, energy management systems, building energy efficiency, renewable energy sources, smart buildings, machine learning.*

Introduction

Modern buildings represent a significant source of energy consumption, creating a range of challenges in the environmental and economic spheres. According to data from the International Energy Agency (IEA), buildings consume approximately 40% of all global energy, with around 30% of this energy being used inefficiently due to outdated technologies and the absence of modern management systems. This situation increases carbon dioxide emissions and negatively affects the sustainable development of cities.

In the Republic of Uzbekistan, the problem of building energy intensity is particularly relevant due to specific climatic conditions: summer temperatures can reach +40 °C, while in winter they can drop to –25 °C. These factors require significant energy expenditures for heating, ventilation, and air conditioning (HVAC) systems. At the same time, the level of automation and energy efficiency of engineering systems in most buildings remains low, leading to increased operating costs and significant energy losses.

The purpose of this study is to substantiate energy management strategies aimed at improving the energy efficiency of buildings in Uzbekistan. To achieve this goal, particular attention should be paid to the following scientific aspects:

- development of a conceptual energy management model, based on the application of intelligent monitoring and analysis systems;
- adaptation of energy management technologies to the specifics of the national energy infrastructure, including limited availability of renewable energy sources;

- integration of machine learning-based forecasting technologies, which will improve the accuracy of energy consumption regulation and reduce excess costs;

- assessment of the environmental and economic effectiveness of the proposed solutions, including reduction of the carbon footprint of buildings and reduction of energy resource costs.

Current research in the field of building energy management shows that the integration of intelligent management systems using the Internet of Things (IoT) and Artificial Intelligence (AI) technologies allows not only to reduce energy costs but also to adapt systems to user behavior and changing environmental conditions. In Uzbekistan, where aging housing stock and underdeveloped infrastructure create additional challenges, more detailed research into the feasibility of using these technologies under existing technical constraints is required.

The issue of building energy efficiency is inextricably linked with sustainable development. In Uzbekistan's context, energy conservation can significantly reduce the load on the energy system, which relies heavily on fossil fuels. Furthermore, improving energy efficiency contributes to reducing building operating costs, which has important social significance given the high share of utility expenses for the population.

To analyze the proposed solutions, modern mathematical models and algorithms can be used:

- forecasting of energy consumption using time series models and machine learning, for example, LSTM or ARIMA. LSTM (Long Short-Term Memory) and ARIMA (Auto Regressive Integrated Moving Average) are two popular methods for time series analysis and forecasting, widely used in various

fields including energy consumption, economics, climatology and others (Table 1).

LSTM is a type of recurrent neural network (RNN) designed to work with time series and sequential data. This model solves the problem of "vanishing gradients", which limits standard recurrent networks, and allows effective processing of long-term dependencies.

The features of LSTM are as follows:

- the structure LSTM consists of specialized memory blocks called "gates" (input, output and forget gates), which regulate the flow of information through the network, allowing the model to store and process information over long time intervals, which is especially important when analyzing data that depends on long-term trends;

- the application of LSTM is effective for forecasting time series where there are complex data dependencies, including those that may change over long time intervals. For example, forecasting energy consumption, where it is important to consider many factors such as weather, time of day and seasonal changes;

- LSTM is based on deep learning methods and solves the problem of long-term data dependency, which is characteristic of time series.

ARIMA (Auto Regressive Integrated Moving Average) - is a statistical model for time series analysis and forecasting. It is based on three components: autoregression (AR), integration (I), and moving average (MA). ARIMA is well-suited for working with time series that exhibit linear dependencies.

The features of ARIMA are as follows:

- the structure ARIMA models a time series as a combination of its past values (AR), forecast errors (MA), and differences (I), which are used to

achieve stationarity of the series, allowing the model to account for trends, seasonality and other dependencies in the data;

- ARIMA is used for forecasting time series with linear dependencies, such as analysis of economic indicators, energy consumption, climate changes, where data are relatively stable or can be brought to a stationary form;

- the ARIMA model is based on the principles of statistics and linear algebra, making it easily interpretable and suitable for analyses with limited computational resources.

Table 1.

Comparative analysis of methods for time series analysis and forecasting

Characteristic	LSTM	ARIMA
Approach	Neural networks	Statistical model
Handling non-linearity	Excellent	Limited
Long-term dependencies	Accounted for	Limited
Ease of interpretation	Low	High
Data requirements	Large volumes of data	Suitable for small datasets
Computational complexity	High	Low

Energy consumption optimization using linear programming or hybrid algorithms makes it possible to account for various factors -weather conditions, user behavior, equipment operating modes, and the specific characteristics of the energy system.

The scientific substantiation of energy management strategies must be based on existing international standards, such as ISO 50001 (energy management systems), as well as national standards and programs adapted to the conditions of Uzbekistan.

Taking into account the climatic conditions of the region, climate modeling methods can be incorporated into the scientific analysis. These methods allow for optimization of heating and cooling systems, which is particularly important under conditions of sharp temperature fluctuations. The implementation of the developed solutions also contributes to the realization of national energy efficiency strategies aimed at ensuring sustainable development

The theoretical foundations of building energy management systems depend on many factors -building design, climatic conditions, level of automation, and user habits. Energy Management Systems (EMS) are used to optimize processes, which include:

- sensors and controllers for monitoring energy consumption;
- Internet of Things (IoT) for connecting all building components into a unified network;
- artificial intelligence - based software, which analyzes data and proposes optimal consumption strategies.

Research shows that the use of EMS can reduce energy costs by 15–30% depending on the level of building automation [1].

Analysis of the current state of energy consumption in buildings in Uzbekistan shows that the main share of energy consumption falls on heating and cooling of buildings. According to data, buildings consume more than 60%

of generated electrical energy; however, the level of automation of management systems remains low, leading to energy overconsumption [6].

The most pressing problems are:

- high wear of thermal and electrical systems;
- limited use of energy - efficient technologies;
- absence of national standards for the design of "smart buildings".

Comparative analysis showed that energy costs in buildings in Uzbekistan are 30–40% higher than in comparable buildings in European Union countries [2].

Methodology for developing energy management strategies is based on the following principles:

1. Data monitoring and analysis -installation of intelligent sensors for real-time energy consumption tracking.
2. Process automation - implementation of systems that automatically regulate temperature, lighting and the operation of engineering systems.
3. Integration of renewable energy sources - use of solar panels and heat pumps to reduce the load on central power grids.

To improve forecasting accuracy, a machine learning methodology is used that analyzes historical data and predicts peak loads, allowing for optimization of equipment operation [4].

Modern approaches to energy management in large industrial and residential facilities are based on the integration of intelligent technologies and innovative systems. The methodology is developed taking into account key principles that ensure efficient energy use, cost reduction, and minimization of environmental impact.

1. Data monitoring and analysis -this principle involves the implementation of intelligent monitoring systems that provide detailed accounting and analysis of energy consumption in real time.

Installation of intelligent sensors -placement of sensors at key elements of the energy system (electrical panels, HVAC systems, lighting fixtures) allows recording of energy consumption at the level of individual devices and rooms. These sensors are equipped with data transmission capabilities to cloud storage or local servers.

Real-time monitoring - the use of software for real-time data visualization enables prompt monitoring and detection of anomalies, such as unauthorized energy consumption or leaks.

Big data analytics - a set of data over long periods is analyzed to identify patterns that can be used to optimize energy consumption.

2. Process automation -the introduction of automated management systems allows reduction of the human factor and improvement of equipment performance.

- **Temperature and lighting control systems** - programmable thermostats regulate the operation of heating and cooling systems depending on the time of day, outdoor temperature, and the presence of people in the room. Similarly, intelligent lighting systems based on motion sensors and natural light level sensors automatically turn lighting on and off.

- **Optimization of engineering system operation** - automated systems monitor the operation of pumps, compressors and ventilation equipment, adapting their operation to current loads. This allows minimization of energy costs while maintaining the required comfort and performance parameters.

3. Integration of renewable energy sources not only reduces electricity consumption from centralized grids but also reduces the enterprise's carbon footprint.

- **Solar panels** - the installation of photovoltaic panels provides direct conversion of solar energy into electricity. Such systems can operate autonomously or be integrated into the facility's general energy network, providing hybrid power supply.

- **Heat pumps** - these devices effectively extract thermal energy from the environment (air, water, or ground) for heating or cooling of rooms. Integration with existing engineering systems allows significant reduction of dependence on fossil fuels.

Forecasting methods using machine learning through technologies play a key role in forecasting energy consumption and load management.

- **Historical data analysis** - machine learning uses arrays of historical energy consumption data, including seasonal, weekly and daily variations, as well as the influence of external factors such as temperature and humidity.

- **Peak load prediction** - algorithms based on regression methods, time series, or neural networks forecast periods of maximum consumption. This allows for proactive measures such as reducing equipment load or redistributing energy costs.

- **Equipment operation optimization** - using forecast data, management systems adjust the operating parameters of engineering networks in advance, avoiding peak loads and ensuring uniform distribution of energy consumption.

The application of this methodology ensures:

- significant reduction of energy resource costs;
- improved equipment reliability through prevention of overloads;

- reduction of carbon footprint through integration of renewable energy sources;
- compliance with environmental and energy standards.

This comprehensive energy management methodology finds application in industry, residential facilities and public buildings, contributing to sustainable development and improvement of energy efficiency.[3]

4. Expected effectiveness and anticipated benefits from the implementation of the proposed energy management strategies.

The implementation of energy management strategies based on the use of intelligent monitoring systems, automation of engineering processes, and integration of renewable energy sources has significant potential for optimizing energy consumption, reducing the carbon footprint, and improving the operational efficiency of buildings. Let us consider the anticipated benefits based on projected indicators for administrative buildings and residential houses:

Table 2.

Expected results and benefits of implementing energy management strategies

Indicator	Administrative building	Residential house	Key achieving factors
Energy consumption reduction (%)	20–30	15–20	Automation of lighting, climate control and household appliance systems
Carbon footprint	10–15	5–10	Integration of solar panels, heat pumps and

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reduction (%)			energy-efficient technologies
Cost savings (%)	25	15	Reduction of electricity costs through system optimization
Comfort improvement	Improved indoor climate quality through automation	Convenience and comfort through intelligent systems	Use of intelligent thermostats and occupancy sensors
Reliability	Reduction of emergency situations through monitoring	Elimination of malfunctions in engineering systems	Implementation of early warning and diagnostic systems
Social significance	Improvement of energy grid stability	Formation of environmentally responsible behavior	Reduction of load on central grids and improvement of energy efficiency

Intelligent energy management systems ensure real-time adaptation of engineering system operation, leading to significant reduction of energy costs. The use of renewable energy sources (solar panels and heat pumps) reduces CO₂ emissions. Optimization of energy consumption reduces electricity costs. Automation of engineering systems improves conditions for users and increases operational reliability. The projected results contribute to compliance

with international sustainable development requirements and foster environmentally conscious user behavior.[10]

These anticipated improvements demonstrate the potential of the proposed strategies for creating energy-efficient and environmentally sustainable facilities. The implementation of such solutions contributes to addressing current energy and environmental security challenges, which represents a significant step toward the modernization of infrastructure in Uzbekistan.

Conclusion. Recommendations and prospects for implementing energy management strategies in the Republic of Uzbekistan.

For the successful scaling and implementation of the proposed energy management strategies, attention must be paid to a number of key areas. These areas include the development of a regulatory framework, government support, and the training of qualified specialists, which together will ensure the effective implementation of energy - efficient technologies.[7]

The development of national standards and regulations governing the design, construction and operation of energy - efficient buildings is a priority task.

- Development of design standards - requirements for thermal insulation, energy-efficient equipment, ventilation and lighting systems;
- Establishment of minimum energy efficiency standards - for all new and renovated real estate properties;
- Integration of international experience -adoption of standards such as ISO 50001 (energy management) and EN 15232 (assessment of energy efficiency of automated building management systems).[5]

These measures will create a unified regulatory framework ensuring improvement of energy efficiency at the national level.

Government support and economic incentives -the implementation of Energy Management Systems (EMS) at the national level is impossible without active government support. Recommended measures include:

- Financial incentives - tax benefits, subsidies and grants for facilities that meet energy efficiency standards;
- Preferential lending - provision of targeted loans for facility modernization and installation of EMS;[9]
- Establishment of support funds - financing of projects related to the implementation of renewable energy sources and energy-saving technologies.

These measures will lower financial barriers to the adoption of modern technologies and accelerate their adaptation.

Training of qualified specialists - a key factor in the successful implementation of energy-saving technologies is the training of professionals proficient in modern methods and tools:

- Development of educational programs -introduction of courses on the design, implementation and operation of “smart” buildings in educational institutions;
- International cooperation -involvement of foreign experts for knowledge exchange and development of educational materials;
- Competency centers -organization of specialized centers for certification and advanced training of specialists.

The training of specialists will provide a professional foundation for the operation of energy-saving systems and technologies.

Prospects for implementation at the national level - comprehensive implementation of EMS will achieve significant improvements in the energy sector and environmental situation:

- Economic benefit -reduction of energy supply costs for households and enterprises by 25%;
- Social benefits -improvement of comfort levels and quality of life through automation and optimization of living conditions;
- Employment growth - increase in the number of jobs in the field of energy -efficient technologies.[8]

Table 3.

Extended table of prospective indicators

Indicator	Projected result	Comment
Energy consumption reduction	20–30%	Through automation and energy-saving technologies
Carbon footprint reduction	15–20%	Use of RES and load reduction on grids
Energy cost savings	25%	Cost reduction for households and businesses
Increase in the number of specialists	+50% by 2028	Educational programs and competency centers
Increase in the share of RES in the energy balance	10–15%	Solar and wind energy integrated into EMS
Quality of life improvement	Comfort improvement	Through automatic indoor climate regulation

	in 70% of facilities	
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Optimization of building energy consumption through the implementation of energy management systems is an important step towards sustainable development. The conducted research showed that the use of EMS reduces energy costs, decreases the carbon footprint, and improves user comfort.[11]

Uzbekistan has significant potential for implementing the proposed solutions thanks to the growing interest in renewable energy sources and government support.

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