JOURNAL OF
MULTIDISCIPLINARY
SCIENCES AND INNOVATIONS

VOLUME 5, ISSUE 05
MONTHLY JOURNALS

ISSN NUMBER: 2751-4390
IMPACT FACTOR: 9,08

UDC: 699.86:004.89:620.9

DESIGNING AND DEVELOPING INNOVATIVE SOLUTIONS FOR ENERGY-EFFICIENT AND SECURITY-INTEGRATED SMART BUILDINGS

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Abstract. This article considers the principles of energy efficiency, operational safety, and digital management as a single design system. The integration of the BIM model, IoT sensors, automated dispatching, fire and evacuation safety, microclimate monitoring, renewable energy sources, and predictive maintenance mechanisms in the design of smart buildings is scientifically and methodologically justified. The study proposes a conceptual model aimed at reducing energy consumption, increasing user safety, and optimizing operational costs throughout the life cycle of a building. The proposed model allows for the interconnection of structural, engineering, and information systems at the design stage, and for data-based decision-making at the operational stage.

Keywords: smart building, energy efficiency, security integration, BIM, IoT, BMS, digital twin, fire safety, predictive monitoring, innovative project solutions.

ENTRANCE

In world construction practice, the issue of designing buildings and structures is no longer limited to structural strength, architectural solutions or the placement of engineering communications. In modern urban planning, a building is interpreted not as a passive object consuming energy, but as a complex technical-cybernetic system that continuously exchanges information with the external climate, user behavior, electrical network, security systems and operational service processes. Therefore, when designing a smart building, it is an urgent scientific and practical task to consider energy efficiency and safety issues not separately, but based on a single integrated management concept.

According to the International Energy Agency, the operational energy consumption of buildings is equivalent to about one third of global final energy consumption. Reports from the UN Global Alliance for Buildings and Construction also note that the building sector accounts for a significant share of energy demand and carbon emissions. This situation requires the development of energy-efficient building materials, effective thermal insulation, automated control and digital monitoring solutions on a scientific basis.

In the conditions of Uzbekistan, this issue is even more important. The processes of urbanization in the country, the expansion of the construction of new housing estates and public buildings, the increase in cooling loads in the summer season, the need to increase the energy efficiency of the existing building stock, and the strategy of transition to a "green economy" create the need to develop a new methodology for designing smart and safe buildings. Energy efficiency is a complex process aimed not only at reducing electricity or heat consumption, but also at ensuring user safety and operational reliability while maintaining the sanitary and hygienic quality of the building's internal environment .

The purpose of the article is to develop scientific and methodological foundations for the design of energy-efficient and security-integrated smart buildings, systematize innovative technological solutions, and propose a conceptual model that can be used in the construction practice of Uzbekistan. Smart building systems were chosen as the object of research, and the subject matter was the integration of energy management, security monitoring, and digital operation mechanisms.

LITERATURE ANALYSIS AND THEORETICAL BASIS

In scientific literature, the concept of "smart building" is usually explained by automated control of building engineering systems, adaptive microclimate to user needs, real-time control of energy resources, seamless operation of security systems, and analytical processing of operational data. In this, Building Management System (BMS), Building Automation and Control System (BACS), Internet of Things (IoT), Building Information Modeling (BIM), Digital Twin, artificial intelligence-based optimization, and cloud monitoring are the main technological components.

The ISO 52120-1:2021 standard defines a common methodology for assessing the contribution of automation, control and technical management functions to the energy performance of buildings. This approach demonstrates the need to determine the energy performance of a smart building not only through thermal insulation or the useful efficiency of equipment, but also depending on the control algorithms, sensors, actuators, operation schedules and the quality of technical management.

The EU Energy Performance of Buildings Directive and the Smart Readiness Indicator concept aim to assess a building's ability to communicate with its users, engineering systems and the energy grid. This experience shows that it is appropriate to assess the technological maturity of a smart building not only by the level of automation, but also by its energy flexibility, indoor environmental quality, ease of maintenance and impact on security.

The classic approach to security integration considers fire alarm, smoke extraction, video surveillance, access control and emergency evacuation systems separately. In the concept of a smart building, these systems are connected to the BMS platform and complement each other in accordance with the real-time situation. For example, in the event of a fire, the ventilation system should limit the spread of smoke, elevators should switch to safe mode, lighting should enhance evacuation routes, and access control should not block exits.

RESEARCH METHODOLOGY

The study used systems analysis, functional modeling, life cycle approach, feasibility study, and risk-based design methods. Through systems analysis, a smart building was considered as a multi-layered object consisting of energy, security, structural, information, and operational subsystems. In functional modeling, the input data, control signals, and output indicators of each subsystem were determined.

The life cycle approach allows for continuous monitoring of energy efficiency and safety indicators during the design, construction, operation, modernization and disposal stages of a building. In this approach, the design solution should be evaluated not only in terms of initial capital costs, but also in terms of energy consumption, maintenance costs, accident risk and user comfort throughout the entire operational period.

the proposed scientific and methodological model, the overall efficiency of a smart building is evaluated through the following integral indicator:

$$\mathbf{I = w_1E + w_2S + w_3C + w_4R + w_5D}$$

where: I — smart building integral performance index; E — energy efficiency index; S — safety and accident risk reduction index; C — user comfort and indoor environment quality; R — operational reliability; D — digital monitoring and data quality; $w_1...w_5$ — weighting coefficients determined depending on the functional task of the project. This formula allows you to adjust the priorities for each type of building: for example, S and C indicators may have a higher weight in schools and hospitals, E and D in office buildings, and R and S in industrial facilities.

ENERGY EFFICIENT SMART BUILDING CONCEPT

The first stage of the concept of an energy-efficient smart building begins with passive design solutions. These include the orientation of the building, rational use of solar radiation, thermal resistance of external barrier structures, glazing coefficient, canopy and facade screens, the possibility of natural ventilation, reduction of thermal bridges and compactness of the building's volume-planning solution. No matter how perfect the automation systems are, real savings will be limited in a building with high passive energy losses.

The second stage is the selection and optimization of active engineering systems. The use of heat pumps, high-efficiency air conditioners, recuperative ventilation, LED lighting, variable frequency pumps and fans, solar photovoltaic panels, solar collectors reduces energy consumption. However, these technologies are most effective when controlled in real time through a BMS, rather than in isolation.

The third stage is energy monitoring and adaptive control. Smart meters are installed in the building for electricity, heat, cold, water and air exchange consumption , and the data is collected on a central platform. Sensors are used to determine the temperature, relative humidity, CO_2 concentration, illumination, number of people and equipment load in the room . Based on this data, the BMS automatically adjusts the heating, cooling, ventilation and lighting modes.

The fourth stage is energy storage and grid-connectedness. Photovoltaic panels, batteries, backup generators, and demand-side management algorithms stabilize the building's energy system. During the day, when solar power is in excess, the storage devices are charged, and during the evening peak load, the consumption is partially covered by the battery. This approach reduces the load on the power grid and ensures the operation of critical safety systems in case of emergencies.

Table 1

Functional classification of smart building energy efficiency solutions

Direction	**Innovative solution**	**Expected result**	**Project stage requirement**
Passive energy saving	Thermal protection, facade screens,	Reduction of heat loss	Joint calculation of architectural and

	optimal orientation		structural solutions
Active engineering systems	Recuperator, heat pump, LED, frequency control	Reduction in electricity and heat consumption	Equipment selection based on real load
Digital monitoring	Smart meters, IoT sensors, BMS	Real-time monitoring and analysis	Defining sensor locations and data protocols
Renewable energy	Photovoltaic panel, collector, battery	Reduction in the share of energy from the grid	Coordination of roof, facade and electrical schemes
Predictive management	AI algorithms, digital twin, service forecasting	Early detection of faults, reducing service costs	Linking BIM model and operational data

SECURITY INTEGRATION AND EMERGENCY RESPONSE

Smart building security systems should allow for early detection of various sources of danger, their rapid assessment and switching engineering systems to the appropriate mode. Such dangers include fire, smoke, gas leakage, electrical short circuit, flooding, unauthorized entry, earthquake, strong wind, structural deformation and technological accidents. The main advantage of security integration is that each sensor does not act as a separate signal source, but as an element of an information system that assesses the overall situation.

Intelligent fire safety integration integrates smoke detectors, heat sensors, sprinkler systems, smoke exhaust ventilation, fire doors, emergency lighting, voice announcements and a digital building plan into a single platform. In the event of an emergency, the system not only sounds an alarm, but also identifies danger zones, dynamically updates evacuation routes, controls ventilation valves and sends precise location information to the responsible services.

From the point of view of seismic resistance and structural safety, an intelligent building can be equipped with accelerometers, deformation sensors, vibration sensors and geodetic monitoring devices on structural elements. Based on this data, the real operational condition of building structures is assessed. Especially in seismically active regions, digital monitoring is of great importance for conducting a rapid technical inspection of a building after an earthquake, temporarily restricting its use or justifying the decision to evacuate.

Cybersecurity is also an integral part of smart building security. When BMS, video surveillance, access control, and energy monitoring are connected via the internet or corporate network, there is a risk of unauthorized access, data modification, or system failure. Therefore, the design should consider network segmentation, encryption, user roles, backup, logging, and emergency manual control modes.

DESIGNING WITH BIM AND DIGITAL TWIN

In the design of smart buildings, the BIM model is not just a three-dimensional graphic image, but also an information base containing structural elements, engineering networks, materials, equipment, operational parameters and maintenance data. Through BIM, architecture, construction, heating and cooling, ventilation, electrical supply, fire safety and automation systems are coordinated in a single environment. This serves to identify collisions in advance, reduce construction errors and form an accurate database for subsequent operation.

The digital twin is a dynamic continuation of the BIM model during the operational phase. It connects data from real sensors to the model and continuously analyzes the state of the building. For example, the design air consumption of the ventilation system is compared with actual sensor data, deviations in energy consumption are detected, user complaints about the room microclimate are linked to technical parameters. As a result, management decisions are based on numerical evidence, not on subjective assumptions.

The digital twin concept is also important for maintenance. Equipment operating hours, vibration, temperature, electrical load and efficiency indicators are collected and the probability of failure is predicted. Such predictive service reduces unplanned downtime, optimizes spare parts procurement and increases building safety.

INNOVATIVE SOLUTIONS SYSTEM

Innovative solutions for energy-efficient and security-integrated smart buildings can be seen in five main blocks. The first block is sensors and data collection infrastructure. This block detects temperature, humidity, CO_2, PM2.5, illumination, number of people, energy consumption, water consumption, smoke, gas and structural vibrations at the room, zone and building levels. The number of sensors should not be excessive, but rather optimally placed in accordance with the project's purpose.

The second block is data transfer and integration protocols. When choosing BACnet, Modbus, KNX, Zigbee, LoRaWAN or other protocols, the type of building, security requirements, distance, data transfer rate and service availability are taken into account. Open protocols are an important prerequisite for future equipment replacement and system expansion.

The third block is control algorithms. In addition to simple schedule control, adaptive algorithms are used that adapt to human presence, weather forecast, electricity tariffs, room occupancy, air quality indicators, and security signals. Artificial intelligence-based algorithms learn from historical data and strive to reduce energy consumption while maintaining comfort levels.

The fourth block is the user interface. Through a mobile application, dispatch panel, web cabinet and evacuation information screens, the user and service personnel monitor the state of the building. The interface should not be overly complicated, and the danger signals should be clear, prioritized and prompt for quick action.

The fifth block is operational analysis and continuous improvement. After the building is commissioned, energy consumption is compared with the project calculations, the causes of deviations are identified, and the algorithms are readjusted. This way, the building does not stop at the “project is commissioned” state, but becomes a system that is constantly improving based on real data.

Table 2

Practical matrix of security and energy efficiency integration

Status	**Energy system reaction**	**Security system response**	**Integration effect**

The room is empty.	Lighting and HVAC power will decrease	Access control in normal mode	Unnecessary energy consumption is reduced
CO₂ exceeded the norm	Ventilation increases air exchange	The user is warned.	A healthy indoor environment is maintained
Fire alarm	Ventilation switches to smoke prevention mode	Evacuation route, notification and doors are controlled	The risk of loss is reduced.
The power supply has been cut off.	Critical systems switch to battery or backup power	Signaling, lighting and communication performance are maintained	Exceptional stability is ensured
Seismic vibration recorded	Critical equipment will go into safe shutdown mode	Evacuation and technical inspection protocol activated	Constructive risk is quickly assessed

APPLICATION OPPORTUNITIES IN UZBEKISTAN

The climatic conditions of Uzbekistan require the design of smart buildings with energy efficiency and security integration based on local characteristics. In the summer season, high temperatures and solar radiation increase the cooling load; in the winter season, the efficiency of the heating system, the thermal protection of external barrier structures and the level of infiltration are of great importance. Therefore, facade solutions, solar protection, natural ventilation, thermal insulation and automatic microclimate control should be modeled based on local climate data.

The country's strategy for transitioning to a "green economy" is aimed at increasing energy efficiency, rational use of resources, and the development of renewable energy sources. Smart buildings can be an important tool for implementing these strategic objectives in the construction sector. In particular, it is advisable to gradually introduce energy monitoring and security integration in government institutions, higher education buildings, hospitals, schools, multi-storey residential buildings, and shopping malls.

The main problems in local practice include insufficient integration of engineering systems in the design process, general writing of technical specifications for BMS, a large number of closed protocols between equipment, a weak training system for service specialists, and limited use of operational data for scientific analysis. To solve these problems, close cooperation between higher education, design organizations, construction companies, and operational services is necessary.

In the national project practice for smart buildings, the technical specifications should include the following mandatory blocks: energy efficiency target indicators; risk scenarios and emergency algorithms; sensor location; data protocols; cybersecurity requirements; LOD/LOI level of the BIM model; commissioning and re-commissioning procedure after commissioning; training program for operational personnel.

RESULTS AND DISCUSSION

As a result of the research, a three-level conceptual model was proposed for designing an energy-efficient and security-integrated smart building. The first level is structural-architectural and passive energy-saving solutions; the second level is automated integration of engineering and security systems; the third level is digital twin, analytical algorithms and predictive operation. These levels should not be isolated from each other, but should be connected through a single information model from the initial stage of the project.

The discussion shows that the effectiveness of a smart building is often determined not by the number of technologies, but by their systematic integration. For example, separately installed solar panels, video surveillance or fire alarms do not automatically raise a building to the level of a smart building. The status of a smart building is based on the analysis of energy, security, comfort and operational data on a single platform, and management decisions are made in a way that is appropriate to the real situation.

The scientific novelty of the proposed model lies in the fact that it considers energy efficiency and safety as complementary, and sometimes mutually limiting, factors. For example, excessively reducing ventilation in order to save energy worsens indoor air quality; while operating security lighting at constant high power increases energy consumption. Integrated management allows for the optimal balancing of these conflicts within regulatory limits.

In practice, this approach allows for reducing energy consumption in building operation, early detection of accidents and malfunctions, increasing user safety, planning service costs, and assessing the actual results of design solutions. This approach is of economic and social importance, especially in social facilities built at the expense of the state budget, in order to reduce life cycle costs and ensure safe operation.

CONCLUSION

Energy-efficient and security-integrated smart buildings are one of the priority areas of the modern construction industry, which solve the tasks of rational use of energy resources, ensuring user safety, and digitizing operational management in a single system.

When designing a smart building, passive energy-efficient architectural solutions, efficient engineering equipment, BMS, IoT sensors, BIM, digital twin, fire and evacuation safety, structural monitoring, and cybersecurity requirements must be coordinated.

The proposed integrated performance model allows for the combined assessment of energy, safety, comfort, reliability, and digital monitoring indicators. This model can be used in practical design by adjusting weight coefficients for buildings with different functional tasks.

The introduction of smart buildings in Uzbekistan will serve the principles of the "green economy", increase energy efficiency, strengthen the safety of social facilities, and accelerate the digital transformation of the construction industry. In the future, it is advisable to implement pilot projects in this direction that take into account the local climate, seismic risk, existing building stock, and economic efficiency.

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