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COMPREHENSIVE ANALYSIS OF FACTORS AFFECTING THE FORMATION OF ENERGY CONSUMPTION IN MULTI-STORY RESIDENTIAL BUILDINGS

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Abstract. This article provides a scientific analysis of the determinants of energy consumption in multi-story residential buildings, examining the structural, engineering, and operational factors involved. It substantiates that high energy demand is frequently caused by inadequate thermal protection of the building envelope, obsolete heating and ventilation systems, ineffective energy management, and inefficient occupant behavior. The study highlights the significance of adopting energy-efficient materials, advanced thermal insulation, high-performance glazing systems, automated control systems, heat recovery ventilation (HRV), and renewable energy sources. The findings are of substantial importance for developing evidence-based recommendations aimed at enhancing the energy performance of multi-story residential buildings.

Keywords: energy consumption, multi-story residential building, energy efficiency, heat loss, building envelope, insulation, engineering systems, energy saving.

Annotatsiya. Ushbu maqolada ko‘p qavatli turar joy binolarida energiya sarfining shakllanish omillari, unga ta’sir etuvchi konstruktiv, muhandislik va ekspluatatsion jihatlar hamda energiya samaradorligini oshirishning zamonaviy usullari ilmiy nuqtai nazardan tahlil qilingan. Binolarda energiya sarfining yuqoriligi ko‘pincha bino qobig‘ining yetarli issiqlik himoyasiga ega emasligi, isitish va shamollatish tizimlarining eskirganligi, energiya boshqaruvining sustligi va foydalanuvchi odatlarining samarasizligi bilan bog‘liq ekanligi asoslab berilgan. Shuningdek, energiya tejamkor materiallar, issiqlik izolyatsiyasi, energiya tejamkor deraza tizimlari, avtomatlashtirilgan boshqaruv, shamollatishdagi issiqlikni qayta tiklash va qayta tiklanuvchi energiya manbalaridan foydalanishning ahamiyati ko‘rsatib berilgan. Tadqiqot natijalari ko‘p qavatli turar joy binolarining energiya samaradorligini oshirish bo‘yicha ilmiy-amaliy tavsiyalar ishlab chiqishda muhim ahamiyatga ega.

Kalit so‘zlar: energiya sarfi, ko‘p qavatli turar joy binosi, energiya samaradorligi, issiqlik yo‘qotilishi, bino qobig‘i, izolyatsiya, muhandislik tizimlari, energiya tejash.

Аннотация. В данной статье с научной точки зрения проанализированы факторы формирования энергопотребления в многоэтажных жилых зданиях, влияющие на него конструктивные, инженерные и эксплуатационные аспекты, а также современные методы повышения энергоэффективности. Обосновано, что высокий уровень потребления энергии в зданиях зачастую связан с недостаточной тепловой защитой оболочки здания, устаревшими системами отопления и вентиляции, слабым управлением энергопотреблением и неэффективными привычками пользователей. Также показана значимость использования энергосберегающих материалов, теплоизоляции, энергоэффективных оконных систем, автоматизированного управления, рекуперации тепла в вентиляции и возобновляемых источников энергии. Результаты исследования имеют важное значение при разработке научно-практических рекомендаций по повышению энергоэффективности многоэтажных жилых домов.

Ключевые слова: энергопотребление, многоэтажное жилое здание, энергоэффективность, теплопотери, оболочка здания, изоляция, инженерные системы, энергосбережение.

In recent years, large-scale systematic efforts have been undertaken in Uzbekistan to construct new industrial facilities, residential housing, educational and medical institutions, and other social infrastructure objects, as well as to reconstruct existing ones, utilizing high-tech construction materials [1]. Creating a safe and comfortable environment for human life is considered the foundation for the socio-economic development of the country. In our country, numerous scientific studies are being conducted using both theoretical and experimental methods aimed at determining energy efficiency in the external building envelopes of residential buildings with various structural solutions.

The Decree of the President of the Republic of Uzbekistan No. PF-60, dated January 28, 2022, "On the Development Strategy of New Uzbekistan for 2022-2026," and Resolution No. PQ-100, dated March 11, 2025, "On Measures to Radically Reform the Heat Energy Supply of Housing and Buildings and Increase Their Energy Efficiency," along with other relevant regulatory legal acts, define the main tasks to be implemented during the year of "Environmental Protection and Green Economy." These tasks focus on providing a stable supply of thermal energy to households, social sector facilities, and business entities through the use of renewable energy devices and resource-saving equipment, reforming the heat supply sector, and reducing energy losses in buildings through innovative technologies [2].

At present, the issue of utilizing energy resources in buildings and structures has become an important scientific and practical problem with not only economic but also ecological and social significance. The growth of the population, acceleration of urbanization processes, expansion of the housing stock, and increased demand for communal services are causing a continuous rise in energy consumption in buildings. This situation is particularly evident in multi-story residential buildings that are in constant use throughout the year.

According to international energy analyses, the building sector accounts for approximately 30% of global energy consumption. At the same time, the main part of the total energy demand in the building sector falls specifically on the residential stock, which further intensifies the urgency of increasing energy efficiency in multi-story residential buildings. Buildings are major consumers of not only thermal energy but also electricity. Therefore, the issue of reducing energy consumption in residential buildings is today regarded as one of the primary directions of resource-saving construction [3].

The high energy consumption in multi-story residential buildings is linked to several factors simultaneously. Firstly, heating, ventilation, hot water supply, lighting, and general-use engineering systems operate continuously in such buildings. Secondly, a large portion of the existing housing stock was built during periods when energy efficiency requirements were not as strictly formed as they are today, and many of them lack sufficient thermal protection in their external building envelopes. Consequently, heat loss is high in many existing buildings, leading to excessive energy consumption to maintain the internal microclimate at standard levels.

Furthermore, technical wear and tear occurring during operation, weak monitoring, insufficient control of ventilation regimes, and user habits are also significant factors that increase energy consumption. From this perspective, the issue of reducing energy consumption in multi-story residential buildings is not a simple task of technical modernization but a complex scientific problem that requires viewing the building as a single energy system. Structural analysis of energy consumption in residential buildings shows that the largest share of total energy expenditure usually falls on heating and hot water supply systems. Some international observations note that these two areas form the bulk of energy consumption in homes. Therefore, any scientific and technical approach to increasing energy efficiency should ideally begin with evaluating the condition of these systems and the structural elements serving them.

At the same time, energy consumption in multi-story residential buildings often increases due to "hidden losses." Examples include incorrectly designed structural joints, uncontrolled heat loss in ventilation, insufficient insulation, losses in heat supply networks, infiltration through window and door gaps, and uneven temperature regimes. In this regard, it is relevant to view a multi-story residential building as a complex energy system rather than a collection of separate elements [4].

One of the factors most strongly influencing the formation of energy consumption in multi-story residential buildings is the thermo-technical properties of the external building envelopes. External walls, the roof, the foundation, the floor, and window and door blocks constitute the main boundary layer between the building's internal microclimate and the external environment. If these structures do not possess sufficient thermal resistance, more energy is required to maintain the internal environment at standard levels. One aspect requiring special attention is the issue of "thermal bridges" (cold bridges). In practice, a sharp increase in heat flows is observed at balcony slabs, column-wall junctions, floor-to-floor joints, nodes around windows, and roof-wall connections. Heat loss at these points not only reduces energy efficiency but also increases the risk of moisture accumulation and biological damage due to the drop in internal surface temperature. Therefore, increasing energy efficiency is inextricably linked not only to increasing material thickness but also to the correct structural solution of the joints.

Window and door systems play a distinct role in the formation of energy consumption in multi-story residential buildings. Windows, on one hand, provide natural lighting and the opportunity to utilize solar heat; on the other hand, they can be a significant source of heat loss as one of the "weakest" parts of the external shell. Especially through old single-pane or wooden-framed windows, not only is heat lost, but air infiltration is also intensified [6].

Air infiltration is an uncontrolled exchange of air that occurs through windows, doors, seams, and joints. Users often perceive this positively as "the house is breathing," but from an energy perspective, this condition leads to the loss of heat in winter and cooled air in summer. Therefore, the issue of window modernization should be considered not only in terms of lowering thermal conductivity but also in conjunction with managing air exchange and preserving the internal microclimate.

Figure 1. Heat loss map in multi-story buildings

HVAC (Heating, Ventilation, and Air Conditioning) and lighting systems are the primary engineering components that shape a building's internal energy loads. Energy consumption increases sharply, especially when these systems operate in uncontrolled or partially controlled modes. Modern approaches note that achieving energy efficiency is more effectively ensured not merely by replacing systems, but through smart control, load optimization, and operation tailored to real-time needs. In most existing residential buildings, the main problem is not the obsolescence of the systems, but their operation in uncontrolled or partially controlled modes. For example, in central heating systems, heat is often delivered in a uniform mode rather than based on the actual needs of the building. Consequently, excessive heating occurs in some rooms while others experience a lack of warmth. This situation forces users to open windows or use additional heaters, leading to "secondary waste" from an energy perspective.

Ventilation systems also frequently cause significant energy losses. In multi-story buildings based on natural ventilation, air exchange is highly dependent on outdoor temperature, wind speed, and internal-external pressure differences, making it inconsistent and unmanageable. As a result, there is insufficient ventilation at times, while at other times, heat is lost due to excessive air exchange [7, 13].

The shape of the building, the exterior surface-to-volume ratio, the number of floors, entrance zones, the presence of a vestibule, the staircase-hall system, and window area and orientation directly affect the energy balance. For instance, irregularly shaped buildings with large exterior surface areas experience greater heat loss. While south-facing facades allow for passive solar heat gain during winter, unshielded glazing can cause overheating in the summer. Therefore, energy efficiency is not just a matter of "construction materials." It is directly linked to the building's overall spatial logic, its position relative to the sun and wind, internal functional connections, and facade composition.

In modern approaches to increasing energy efficiency, the principle of "measure, monitor, and control" holds a special place. Often, energy consumption in multi-story residential buildings is inflated, yet exactly where and when the excess consumption occurs remains unidentified. Therefore, introducing meters, sensors, block-based monitoring, and smart control systems is an essential tool for energy efficiency [15].

Modern smart control tools allow for real-time monitoring of energy consumption in buildings, load optimization, and steering user behavior toward energy-saving modes. Thus, monitoring and automated control systems are regarded as vital instruments for enhancing energy efficiency. Before developing effective measures to reduce energy consumption in multi-story residential buildings, it is necessary to determine the building's current energy status. From this perspective, an energy audit is a crucial diagnostic tool that allows for the identification of energy flows, heat loss zones, the load levels of engineering systems, and sources of excess consumption [8, 14].

As a result of an energy audit, the baseline level of energy consumption in the building is determined, and priority areas for modernization measures are established. In this process, thermal imaging, inspection of structural joints, analysis of meter data, study of user patterns, and evaluation of engineering system efficiency are of great importance. Therefore, any technical decision regarding energy efficiency improvements should ideally be made based on audit data.

Analysis shows that viewing the issue of energy consumption in multi-story residential buildings solely as "heat loss" or "electricity consumption" is insufficient. This issue is formed at the intersection of structural, engineering, operational, and social factors. Consequently, the proposed measures for increasing energy efficiency must be systemic in nature, rather than focusing on a single direction.

Modern research indicates that applying several modernization measures together yields higher results than any single technology. Therefore, a comprehensive modernization approach is more effective than individual technical solutions regarding energy conservation. This issue is particularly urgent for the existing multi-story residential stock. While designing new buildings to be energy-efficient is relatively easy, retrofitting occupied multi-story buildings to be energy-efficient is a more complex task structurally, economically, and organizationally.

From this viewpoint, gradual modernization of existing buildings based on energy audits can be seen as the most appropriate direction [14].

Practical studies conducted on high-rise residential buildings show that deep energy modernization can result in a very large reduction in total energy consumption. In some cases, comprehensive reconstruction measures have been recorded to sharply decrease a building's energy intake. This demonstrates that scientifically grounded modernization approaches for increasing energy efficiency also yield high practical results.

Conclusion.

In summary, energy consumption in multi-story residential buildings is a multi-factor and complex system. The thermo-technical state of external building envelopes, the quality of window and door systems, the efficiency of engineering networks, architectural-planning solutions, ventilation regimes, operational status, and user behavior all play a vital role in its formation. Research results show that a single individual technical measure is not enough to reduce energy consumption; instead, a comprehensive approach that considers the building as a unified energy system is required. Recommended key directions for increasing energy efficiency include strengthening the thermal protection of the building shell, introducing energy-efficient window and facade systems, modernizing heating and ventilation systems, utilizing automated control and monitoring systems, and progressively integrating renewable energy sources. This approach serves to reduce energy consumption in multi-story residential buildings, cut operational costs, increase living comfort, and ensure the long-term sustainability of the building stock.

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