ENERGY EFFICIENCY IN THE RESTORATION OF HISTORICAL AND ARCHITECTURAL HERITAGE SITES

Kim Tatyana Glebovna
PhD student of Turin Polytechnic University in Tashkent

Abstract. In the context of climate change and increasing energy consumption, improving the energy efficiency of historic buildings has become essential for their preservation. Cultural heritage structures often exhibit low thermal performance and outdated engineering systems, complicating their operation. Using Uzbekistan—home to more than 8,000 heritage sites—as an example, the need for adaptive modernization of traditional buildings is emphasized. International experience demonstrates successful integration of energy-efficient technologies while maintaining authenticity. Particular attention is given to digital modeling, microclimate analysis, and the use of compatible materials. Energy-efficient restoration is considered a key tool for extending the lifespan of heritage assets and ensuring their sustainable development.

Keywords: energy efficiency, cultural heritage, restoration, building modernization, renewable energy sources, traditional materials, sustainable development, adaptive modernization, thermal performance, cultural authenticity, BIM modeling, architectural conservation, climate modeling, Uzbekistan.

Annotatsiya. Iqlim o‘zgarishi va energiya iste’molining ortib borishi sharoitida tarixiy binolarning energiya samaradorligini oshirish ularni saqlab qolishning muhim omiliga aylanmoqda. Madaniy meros obyektlari, odatda, past issiqlik-texnik ko‘rsatkichlarga va eskirgan muhandislik tizimlariga ega bo‘lib, ularning ekspluatatsiyasini murakkablashtiradi. O‘zbekistonda 8000 dan ortiq meros obyektlari mavjudligi misolida an’anaviy binolarni moslashtirilgan modernizatsiya qilish zarurligi ta’kidlanadi. Jahon tajribasi autentiklikni saqlagan holda energiya samarador texnologiyalarni muvaffaqiyatli joriy etish mumkinligini ko‘rsatadi. Raqamli modellashtirish, mikroiqlim tahlili va mos materiallardan foydalanishga alohida e’tibor qaratiladi. Energiya samarador restavratsiya yodgorliklarning xizmat muddatini uzaytirish va ularning barqaror rivojlanishini ta’minlashning asosiy vositasi sifatida qaraladi.

Kalit so‘zlar: energiya samaradorligi, tarixiy meros, restavratsiya, binolarni modernizatsiya qilish, qayta tiklanuvchi energiya manbalari, an’anaviy materiallar, barqaror rivojlanish, moslashtirilgan modernizatsiya, issiqlik-texnik xususiyatlar, madaniy autentiklik, BIM-modellashtirish, arxitekturani saqlash, iqlimiy modellashtirish, O‘zbekiston.

Абстракт. В условиях климатических изменений и роста энергопотребления повышение энергоэффективности исторических зданий становится важным условием их сохранения. Объекты культурного наследия часто имеют низкую теплотехническую эффективность и устаревшие инженерные системы, что усложняет их эксплуатацию. На примере Узбекистана, где насчитывается более 8000 памятников, подчёркивается необходимость адаптивной модернизации

традиционных зданий. Мировой опыт демонстрирует успешную интеграцию энергоэффективных технологий при сохранении аутентичности. Особое внимание уделяется цифровому моделированию, анализу микроклимата и использованию совместимых материалов. Энергоэффективная реставрация рассматривается как ключевой инструмент продления жизненного цикла памятников и обеспечения их устойчивого развития.

Ключевые слова: энергоэффективность, историческое наследие, реставрация, модернизация зданий, возобновляемые источники энергии, традиционные материалы, устойчивое развитие, адаптивная модернизация, теплотехнические характеристики, культурная аутентичность, BIM-моделирование, сохранение архитектуры, климатическое моделирование, Узбекистан.

The issue of improving energy efficiency in the construction sector has become particularly relevant against the backdrop of global climate change and the sustainable growth of energy consumption. Historical buildings, which constitute a significant part of the architectural heritage, possess high cultural value but often do not meet modern standards for thermal performance, engineering systems, and energy consumption. Their structural systems and materials, designed for different climatic and operational conditions, frequently result in high heat losses, insufficient comfort, and increased operating costs.

In Uzbekistan, the problem of energy-efficient modernization of historical buildings is especially significant, as the country has registered more than 8,000 cultural heritage monuments [1], of which over 2,200 are architectural objects located in Samarkand, Bukhara, Khiva, Shakhrisabz, and Tashkent. Buildings constructed from traditional materials—clay, brick, lime mortars, and wood—have been in use for centuries, requiring methods that ensure both the preservation of authenticity and the improvement of energy sustainability.

Global practice demonstrates a stable trend toward reducing energy consumption through the adoption of modern technologies. In the United States, energy use in the residential and commercial sectors decreased from 40% in 2006 to 27.6% in 2023 [2]. In EU countries, buildings consume about 40% of energy and account for 36% of CO_2 emissions, making them a key element in decarbonization policies. Special attention is paid to the modernization of historical building stock, as approximately 90% of the buildings that will be in use by 2050 have already been constructed. The most challenging to renovate are buildings erected before 1919 or 1960: they lack insulation, have poor performance of enclosing structures, and are equipped with outdated engineering systems [3].

One promising direction is the integration of renewable energy sources—photovoltaic panels, solar collectors, heat pumps, and geothermal systems. However, such interventions require special restoration approaches, as any modifications must not compromise the historical appearance of the building. European examples demonstrate the successful integration of renewable energy technologies: solar panels on Gloucester Cathedral in the UK or the PV system on a church in Leipzig show that modern energy

technologies can be harmoniously incorporated into historic environments while respecting restoration principles [4].

The modernization of historical buildings is complicated by numerous constraints: the impossibility of altering facades, the use of traditional materials with low thermal efficiency, high sensitivity of structures to moisture and temperature fluctuations, and the absence or critical obsolescence of engineering systems. Standard modern solutions—plastic windows, synthetic insulation materials, ventilated facades—are often unacceptable as they compromise the historical authenticity of the object. Therefore, the application of energy-efficient technologies should rely on specialized methods: using breathable natural insulators, integrating engineering systems discreetly, employing capillary panels, applying traditional ventilation and cooling techniques, and creating passive thermal protection systems that preserve the building's exterior appearance.

In Uzbekistan, despite active implementation of "green" technologies and the development of energy-saving programs, the modernization of historical buildings faces several barriers. These include the lack of a regulatory framework for energy-efficient restoration, insufficient research on the thermal characteristics of traditional materials, absence of systematic monitoring of building conditions, and a limited number of national examples of successful modernization. The challenge is further complicated by the high sensitivity of structures to interventions: even minor changes can compromise their stability. Nevertheless, the country has significant potential for developing a comprehensive methodology that considers climatic conditions, the specifics of Central Asian architecture, and contemporary sustainable architecture requirements.

A key approach is adaptive modernization, which involves the phased and careful introduction of energy-efficient elements. This approach is based on analyzing microclimate conditions, structural features of the building, using traditional construction techniques, and employing digital tools—BIM modeling, 3D scanning, and climate simulation. Adaptive solutions allow the integration of energy-efficient systems without compromising the historical appearance. Such solutions include interior insulation with controlled vapor permeability, regulation of natural ventilation, low-temperature heating systems, installation of thin-film solar panels in hidden areas, and the use of semi-transparent modules.

Thus, achieving low energy consumption in historical buildings is a complex but feasible task, requiring an interdisciplinary approach, individualized design, and careful integration of modern technologies with traditional construction methods. Uzbekistan has all the prerequisites for establishing a national system of energy-efficient restoration. This involves developing specialized regulations, training professionals, creating research laboratories, developing monitoring and digital modeling systems, and expanding international cooperation. A comprehensive approach will ensure the preservation of architectural heritage while simultaneously enhancing the energy sustainability of historical buildings, integrating them into the modern urban environment.

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