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IMPROVING THE ENERGY EFFICIENCY OF HISTORICAL MONUMENTS AS A FACTOR IN THE SUSTAINABLE DEVELOPMENT OF THE BUILT ENVIRONMENT

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ABSTRACT:

This article examines the improvement of energy efficiency in historical monuments as a factor in the sustainable development of the built environment. It analyzes contemporary renovation methods, including passive and active technologies, as well as the limitations of applying them in historic settings. Principles for integrating energy-efficient solutions with due regard to architectural and climatic characteristics are proposed. The article demonstrates that modernization can reduce energy consumption, extend the service life of buildings, and preserve their cultural value.

Introduction. In the context of the transition towards sustainable architecture and intensifying climate change, improving the energy efficiency of historic buildings is becoming increasingly important. Architectural heritage is not only of cultural and historical value but also represents a substantial part of the existing building stock that needs to be adapted to contemporary energy-saving requirements. However, implementing energy-efficient solutions in such buildings is challenging because it is necessary to maintain a balance between authenticity, architectural expression, and historical integrity.

Working with historic buildings requires a sensitive approach that takes into account their structural systems, construction materials, and artistic and compositional characteristics [1]. This makes it necessary to develop specialized modernization methods.

Therefore, improving the energy efficiency of historic buildings is an interdisciplinary task that requires the integration of architectural, engineering, environmental, and economic approaches in order to balance heritage conservation with the contemporary requirements of sustainable development.

Methods. This study adopts an interdisciplinary approach combining architectural and historical analysis, engineering modelling, and environmental assessment. This approach makes

it possible to consider historic buildings as complex systems comprising cultural, structural, and energy-related components, and to develop well-founded modernization strategies (Figure 1).



Figure 1. Author's diagram: "The building as a multi-component system."

Architectural and historical analysis aims to identify the value-bearing characteristics of buildings, including their spatial layout, structural features, materials, and the degree to which authentic elements have been preserved. This stage is essential for defining acceptable limits of intervention and establishing principles for adapting energy-efficient solutions in accordance with cultural heritage protection requirements.

The engineering and technical component is based on thermodynamic modelling to assess thermal performance, identify heat losses, and determine the potential for improving energy efficiency. The modelling takes actual operating conditions and modernization scenarios into account, supporting reliable assessments and predictions of the effectiveness of proposed solutions. Building services are also analyzed to identify opportunities for optimization while minimizing intervention in the historic structure [2].

The assessment of renewable energy integration includes an analysis of solar, geothermal, and other systems, taking into account architectural constraints and the need to preserve the appearance of buildings (Figures 2–3). Energy-efficient technologies are considered in terms of their compatibility with the historic environment and the minimization of visual impact [3].



Figure 2. Solar panels at St Peter's Basilica, Vatican City.



Figure 3. Lutheran Church in Meissen, Germany.

The methodology also includes a life-cycle assessment of buildings (materials, construction, operation, and end-of-life), making it possible to account for their overall environmental impact and select sustainable solutions [4]. The relevance of this approach is associated with the significant contribution of the construction sector to energy consumption and CO_2 emissions [5].

Thus, the proposed set of methods provides a comprehensive assessment of the opportunities for improving the energy efficiency of historic buildings and establishes a basis for developing adaptive strategies for their sustainable modernization.

Results. The analysis shows that the energy efficiency of historic buildings can be significantly improved without altering their appearance through adaptive modernization with limited economic and environmental costs. Effectiveness is achieved through an integrated approach involving compatible materials and technologies that reduce energy consumption, improve thermal comfort, and lower CO_2 emissions. The greatest benefits can be achieved through comprehensive modernization, including improved thermal insulation, increased airtightness while maintaining vapour permeability, upgrading heating and ventilation systems, and integrating renewable energy sources with minimal visual impact.

Thus, the findings confirm that applying adaptive, evidence-based approaches to the modernization of historic buildings can substantially improve their energy efficiency without compromising authenticity, thereby supporting sustainable development and the rational use of resources in the construction sector.

Discussion. The findings confirm that improving the energy efficiency of historic buildings is possible through comprehensive adaptive modernization involving innovative insulation materials, optimization of HVAC systems, and the integration of renewable energy sources with minimal impact on architectural appearance. An important priority is the development of specialized energy-efficiency assessment systems that take account of both the technical and cultural characteristics of buildings, since existing rating systems do not adequately reflect the specific nature of heritage assets [6]. Modernization strategies should be tailored to each building, considering its age, materials, and state of preservation, in order to achieve a balance between

conservation and energy efficiency [7]. Energy audits and modernization require an interdisciplinary approach that combines engineering solutions with conservation principles, including minimal intervention, reversibility, and the preservation of authenticity [8].

Thus, the discussion confirms that successful energy-efficient modernization of historic buildings requires the integration of engineering innovations, architectural conservation principles, and adaptive management strategies that support sustainable development without compromising the cultural identity of the buildings.

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List of illustrations.

Figure 2. Solar panels at St Peter's Basilica, Vatican City.Солнечные панели Ватикана: Церковь на острие прогресса

Figure 3. SOLARWATT solar panels, Germany.Солнечные панели SOLARWATT, Германия

Figure 1. Author's diagram.