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Review paper

RETROFITTING EXISTING MASONRY BUILDINGS TO PASSIVE HOUSE STANDARDS: CHALLENGES AND TECHNICAL SOLUTIONS

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Abstract

The renovation of the existing building stock is essential for reducing energy consumption and improving indoor environmental quality. Retrofitting existing masonry buildings to high energy-performance standards is particularly challenging because energy-efficiency measures must be adapted to the characteristics of the existing building fabric, moisture behaviour, architectural constraints, and technical feasibility. This paper presents a structured analytical review of the main technical challenges and retrofit measures associated with the application of Passive House principles to existing masonry buildings. Relevant scientific and professional literature was comparatively analyzed and organized according to the principal retrofit measures and their reported effects on building performance. The analysis considers improvements to the thermal envelope, thermal bridge reduction, airtightness, high-performance windows and doors, controlled ventilation with heat recovery, solar control, moisture management, and efficient domestic hot water systems. A criterion-based qualitative framework is used to synthesize the relative contribution of these measures to energy efficiency, thermal comfort, indoor air quality, moisture protection, and building durability. The results indicate that the effectiveness of individual measures depends strongly on their interaction with other retrofit interventions and on the characteristics of the existing building. Continuous insulation, thermal bridge reduction, airtightness, high-performance openings, and mechanical ventilation with heat recovery form the core of an integrated high-performance retrofit strategy, while moisture management represents a cross-cutting requirement. The study provides a structured synthesis of the main technical relationships, performance contributions, and implementation constraints reported in the literature. It concludes that substantial improvements can be achieved through an integrated, building-specific approach, whereas the feasibility of attaining the full Passive House standard should be assessed individually for each existing masonry building.

Key words: *Passive House; EnerPHit; existing masonry buildings; energy retrofit; thermal comfort; airtightness; moisture protection; building durability*

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1. INTRODUCTION

The improvement of the existing building stock represents one of the main challenges in reducing operational energy consumption and improving the overall performance of the built environment. A considerable proportion of existing residential buildings was constructed before the introduction of contemporary energy-efficiency requirements and is characterized by insufficient thermal insulation, uncontrolled air leakage, thermal discontinuities, and inadequate building services. In addition to high energy demand, the ageing of materials and prolonged environmental exposure may affect the functional performance and durability of building components.

Existing masonry buildings present particular challenges for deep energy renovation. Their geometry, wall composition, structural characteristics, and state of preservation often limit the direct application of solutions developed for new buildings. In addition, the improvement of thermal performance may interact with structural requirements, architectural restrictions, and the heat and moisture behaviour of the existing envelope. The integrated consideration of seismic safety and energy retrofit has, for example, been identified as an important aspect in the renovation of existing masonry buildings [1].

The application of Passive House principles offers a comprehensive approach to reducing building energy demand through a highly efficient thermal envelope, minimization of thermal bridges, improved airtightness, high-performance windows and doors, and controlled mechanical ventilation with heat recovery. For existing buildings, these principles can also be applied through the EnerPHit renovation concept, which recognizes the specific technical constraints associated with retrofitting existing structures [6,7]. Previous studies have investigated passive retrofit scenarios and energy-efficiency strategies for existing and heritage buildings under different climatic and technical conditions [2–5].

However, individual retrofit measures cannot be evaluated independently. The improvement of insulation without adequate treatment of thermal bridges may leave areas of increased heat loss and condensation risk. Similarly, increased airtightness requires an appropriate ventilation strategy, while modifications to the thermal envelope can alter the moisture behaviour and drying potential of existing masonry walls. The effectiveness of windows, solar gains, and daylighting also depends on orientation, shading, and the characteristics of the overall envelope.

The objective of this study is therefore to provide a structured comparative synthesis of the principal technical measures associated with the application of Passive House principles to existing masonry buildings. The paper reviews their primary functions, reported performance effects, interactions, and principal implementation constraints. A criterion-based qualitative assessment is further applied to compare their relative contribution to energy efficiency, thermal comfort, indoor air quality, moisture protection, and building durability. The contribution of the study lies in organizing these interconnected measures within a common analytical framework that supports the preliminary evaluation of integrated retrofit strategies for existing masonry buildings.

2. MATERIALS AND METHODOLOGY

2.1 Analytical approach and source selection

The study was conducted as a structured analytical literature review. It does not include an original case study, field measurements, calibrated building-energy modelling, or independent simulation of retrofit scenarios. Accordingly, the results should be interpreted as a comparative synthesis of the findings reported in existing scientific and professional literature rather than as building-specific quantitative predictions.

The review focused on literature addressing energy renovation of existing and heritage buildings, Passive House and EnerPHit principles, passive retrofit scenarios, and technical challenges associated with the improvement of existing building performance. Priority was given to studies discussing one or more of the following aspects: thermal insulation, thermal bridges, airtightness, ventilation, windows and doors, solar gains and shading, moisture-related risks, and the technical applicability of high-performance retrofit measures [1–8].

The selected sources were classified according to the principal retrofit measures addressed and the building-performance aspects discussed. Because the reviewed studies were conducted for different building types, climates, and methodological conditions, their results were not combined into a single quantitative dataset.

2.2 Criterion-based assessment framework

The analysis considers nine principal measures: continuous thermal insulation, thermal bridge reduction, airtightness improvement, high-performance windows and doors, mechanical ventilation with heat recovery, solar shading, daylighting and controlled solar gains, moisture management, and efficient domestic hot water heating and distribution.

Each measure was comparatively assessed according to five performance criteria:

- Energy efficiency – contribution to reducing energy demand and heat losses;
- Thermal comfort – contribution to stable and acceptable indoor thermal conditions;
- Indoor air quality – contribution to controlled air exchange and indoor environmental quality;
- Moisture protection – contribution to reducing condensation and excessive moisture accumulation;
- Building durability – contribution to preserving the long-term functional performance of building components.

A three-level qualitative scale was used: 1 – limited or indirect contribution; 2 – moderate or context-dependent contribution; and 3 – high and direct contribution. Ratings reflect the directness and relative significance of each measure's contribution to the assessed performance criterion.

Table 1. Analytical framework used for the comparative synthesis

Analytical component	***Assessment focus***
Retrofit measure	Principal technical intervention
Primary function	Main building-performance problem addressed
Energy efficiency	Reduction of energy demand and heat losses
Thermal comfort	Improvement of indoor thermal conditions
Indoor air quality	Contribution to controlled air exchange
Moisture protection	Reduction of condensation and moisture risks
Building durability	Contribution to long-term component performance
Interactions	Relationship with other retrofit measures
Constraints	Building-specific and implementation limitations

3. PASSIVE HOUSE RETROFIT STRATEGIES AND TECHNICAL SOLUTIONS

The principal retrofit measures considered in the application of Passive House principles to existing masonry buildings are illustrated in Figure 1. The measures include improvements to the thermal envelope, thermal bridge reduction, airtightness, high-performance windows, shading, controlled ventilation, daylight utilization, moisture management, and efficient domestic hot water distribution.

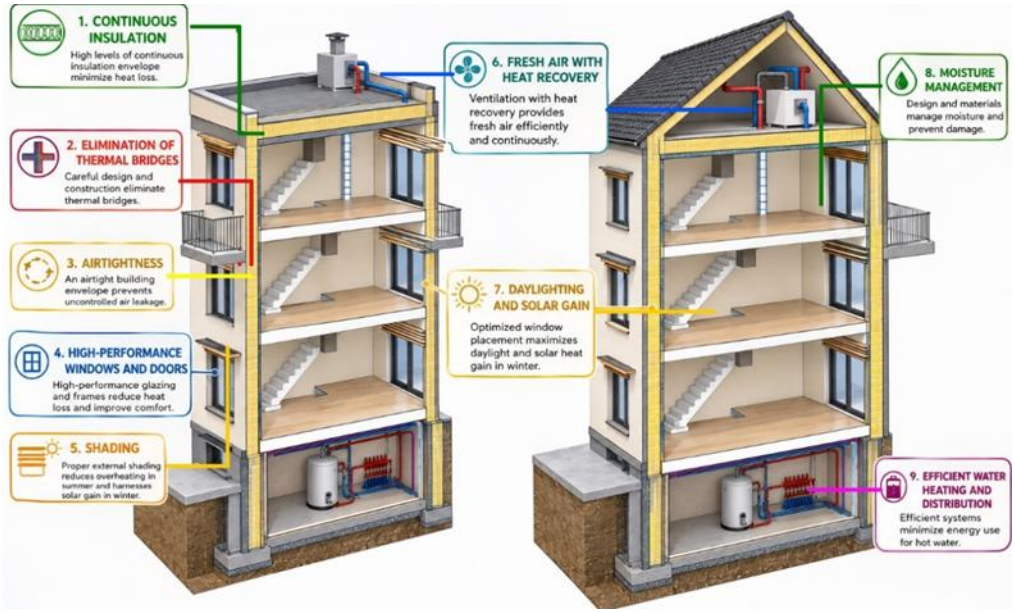


Figure 1. Comparative schematic illustration of Passive House design strategies for flat- and pitched-roof buildings (Author's own illustration, created with the assistance of AI-based tools)

3.1 Thermal envelope and thermal bridge reduction

Improvement of the thermal envelope is one of the primary strategies for reducing transmission heat losses in existing buildings. Continuous thermal insulation can improve the thermal resistance of walls, roofs, and floors while increasing internal

surface temperatures and contributing to improved thermal comfort. Its effectiveness, however, depends on the continuity of the insulation layer and its compatibility with the existing construction [3–6,8].

Thermal bridges represent localized areas of increased heat transfer caused by geometric conditions, material discontinuities, or interruptions in the insulation layer. In existing masonry buildings, they commonly occur at floor and roof junctions, structural elements, balconies, and window reveals. Their reduction is important not only for lowering heat losses but also for increasing internal surface temperatures and reducing the risk of surface condensation and mold growth [5–8].

The position of insulation is particularly important in existing masonry construction. External insulation generally protects the original wall from external temperature variations, whereas internal insulation may be necessary where façade alterations are restricted. However, internal insulation can modify the temperature and moisture conditions within the existing wall and reduce its drying potential. Its application therefore requires careful consideration of material compatibility and moisture-related risks [3–5].

High-performance windows and doors form an integral part of the improved thermal envelope. Their contribution depends on glazing and frame properties, airtightness, installation quality, and the treatment of the connection between the opening and the surrounding wall. Poorly designed installation details may create thermal bridges or air leakage paths that reduce the effectiveness of otherwise high-performance components [6–8].

3.2 Airtightness and controlled ventilation

Airtightness limits uncontrolled air leakage through joints, cracks, penetrations, and construction interfaces. Its primary contribution is the reduction of ventilation-related heat losses and uncontrolled drafts. In existing buildings, achieving a continuous air barrier can be particularly challenging because of irregular surfaces, existing cracks, multiple material junctions, and service penetrations [5,6].

Airtightness should not, however, be considered independently of ventilation. Reducing uncontrolled infiltration increases the importance of a designed strategy for supplying fresh air and removing indoor pollutants and moisture. Mechanical ventilation with heat recovery is therefore a key complementary measure in high-performance retrofits. It enables controlled air exchange while recovering part of the thermal energy from the outgoing air, contributing simultaneously to energy efficiency and indoor air quality [6,7].

The interaction between airtightness and ventilation illustrates the integrated character of Passive House-oriented renovation. Airtightness alone does not improve indoor air quality; its benefits in this respect depend on the implementation of adequate ventilation. Similarly, the effectiveness of mechanical ventilation may be reduced where excessive uncontrolled air leakage remains present. The feasibility of installing heat recovery ventilation in existing buildings may also be constrained by the space required for ducts and equipment, service-routing possibilities, noise control, and access for maintenance.

3.3 Solar control and daylight utilization

Windows provide access to daylight and solar energy but may also increase overheating risk. Appropriate use of daylight can reduce the demand for artificial lighting, while controlled solar gains may contribute to reduced heating demand during suitable periods. These effects depend strongly on orientation, glazing characteristics, window size, climate, and building geometry [2–4].

Solar shading is therefore an important complementary measure. Its primary role is to limit unwanted solar gains and reduce overheating risk, particularly during periods of high solar exposure. External shading can be especially effective because it intercepts solar radiation before it enters the building. However, shading must be coordinated with daylight requirements and beneficial winter solar gains. Excessive shading may reduce useful daylight, while insufficient solar control may compromise thermal comfort [2,3].

In existing buildings, modifications to windows or the installation of external shading may be limited by façade geometry and architectural or heritage restrictions. Consequently, the potential for optimizing daylight and solar performance must be assessed in relation to the characteristics of the individual building.

3.4 Moisture management and building durability

Moisture management is a cross-cutting requirement in the renovation of existing masonry buildings. The introduction of insulation, improved airtightness, and changes in ventilation conditions can alter the original heat and moisture balance of the building envelope. If these changes are not appropriately assessed, they may increase the risk of surface or interstitial condensation, mold growth, and material deterioration [3–5].

This issue is particularly relevant for internally insulated masonry walls. Although internal insulation can significantly reduce heat losses, it may lower the temperature of the existing masonry and alter its drying potential. The suitability of the proposed assembly therefore depends on the characteristics and initial condition of the wall, climatic exposure, moisture sources, and the properties of the new retrofit layers [3–5].

Moisture protection is closely connected with building durability. Repeated or persistent exposure to moisture can affect the functional performance of masonry and other building materials. Appropriate treatment of thermal bridges, airtightness, ventilation, and insulation should therefore be considered together as part of a moisture-safe and durable retrofit strategy. The EnerPHit and Passive House criteria also recognize moisture-related protection and the prevention of excessive indoor humidity as relevant aspects of high-performance building design [7].

3.5 Efficient domestic hot water systems

Efficient domestic hot water systems contribute primarily to the reduction of operational energy consumption. Their effectiveness may be improved through efficient water-heating equipment, reduced distribution losses, insulated pipework, and appropriate system design. Unlike envelope and ventilation measures, their direct influence on thermal comfort, indoor air quality, and moisture protection is limited.

Nevertheless, they form part of the overall strategy for reducing the operational energy demand of renovated buildings and should be coordinated with other building services measures [2,7].

4. COMPARATIVE SYNTHESIS AND DISCUSSION

The findings presented in Section 3 were synthesized using the assessment framework described in Section 2.2. The ratings presented below do not represent measured or simulated performance values. They provide a comparative qualitative interpretation of the primary and secondary effects of individual retrofit measures based on the reviewed literature and their technical function, presented in Table 2.

Table 2. Qualitative assessment of the principal Passive House retrofit measures

Retrofit measure	Energy efficiency	Thermal comfort	Indoor air quality	Moisture protection	Building durability
Continuous insulation	3	3	1	2	3
Thermal bridge reduction	3	3	1	3	3
Airtightness improvement	3	3	3*	3	2
High-performance windows and doors	3	3	1	2	2
Mechanical ventilation with heat recovery	3	2	3	2	2
Solar shading	2	3	1	1	1
Daylighting and controlled solar gains	2	2	1	1	1
Moisture management	2	2	2	3	3
Efficient domestic hot water systems	3	1	1	1	1

Assessment scale: 1 – limited or indirect contribution; 2 – moderate or context-dependent contribution; 3 – high and direct contribution.

**Airtightness alone does not provide fresh air. Its contribution to indoor air quality depends on integration with an adequate controlled ventilation strategy.*

The assessment indicates that continuous insulation and thermal bridge reduction have the strongest combined influence on energy efficiency, thermal comfort, moisture protection, and the durability of the building fabric. This is consistent with their direct role in reducing heat transfer and preventing low internal surface temperatures. However, insulation cannot be considered independently of moisture behaviour, particularly in existing masonry walls and internally insulated assemblies [3–6].

Airtightness and mechanical ventilation with heat recovery form another closely interconnected group. Airtightness reduces uncontrolled air leakage and associated

heat losses, while controlled ventilation provides the required air exchange and enables heat recovery. Their combined application is therefore more important than the performance of either measure considered in isolation [6,7].

High-performance windows and doors also contribute directly to energy efficiency and thermal comfort, but their overall effectiveness depends on installation details and their integration with the surrounding insulation and airtightness layers. Solar control and daylighting have a more context-dependent contribution because their effects vary according to orientation, climate, glazing characteristics, and the balance between beneficial and unwanted solar gains [2–4].

Moisture management has a distinct role within the framework. Its strongest contribution is to moisture protection and building durability, but it also interacts with energy efficiency, thermal comfort, and indoor air quality. This confirms that moisture safety should not be treated as a separate final-stage check but as a condition that must be considered throughout the development of the retrofit strategy [3–5].

Efficient domestic hot water systems have a different functional profile. Their primary contribution is to reducing operational energy demand, whereas their direct influence on envelope performance and indoor environmental quality is limited.

Overall, the results demonstrate that high-performance renovation should be based on the coordinated selection of complementary measures. The improvement of one component may be insufficient or may even create new technical risks when considered separately. For example, increased insulation without adequate thermal bridge treatment may leave localized areas vulnerable to condensation, while increased airtightness without controlled ventilation may adversely affect indoor air quality. Similarly, internal insulation must be evaluated in relation to the moisture behaviour of the existing wall.

The feasibility of achieving the full Passive House standard therefore depends on building-specific conditions. Existing structural configurations, architectural or heritage restrictions, irregular construction details, moisture-related risks, limited space for technical systems, and the cost or complexity of interventions may restrict the application of some measures [1,3–7]. In such cases, the application of Passive House principles through an EnerPHit-oriented renovation approach may provide a realistic pathway for achieving substantial performance improvements while accounting for the limitations of the existing building [6,7].

5. LIMITATIONS OF THE REVIEW

This study is based on a structured analytical review and qualitative synthesis of existing literature. It does not include a primary case study, field measurements, or independent simulation of retrofit scenarios; therefore, the findings should not be interpreted as building-specific quantitative predictions. The qualitative ratings represent a comparative interpretation of the reported effects and technical functions of retrofit measures and may vary according to climate, building geometry, wall composition, the condition of the existing fabric, and the detailed design of the intervention. In addition, the reviewed literature includes different building types and

methodological approaches, which prevents the direct aggregation of reported numerical results. The proposed framework is intended to support the preliminary comparison of retrofit measures and does not replace project-specific energy, hygrothermal, structural, or economic assessment. Future research should apply and validate the framework through representative case studies and quantitative analyses of alternative retrofit scenarios.

6. CONCLUSION

The renovation of existing masonry buildings according to Passive House principles requires an integrated approach in which individual measures are selected and designed in relation to the existing building fabric and their interaction with other interventions. The application of high-performance components alone cannot ensure an effective retrofit if the continuity of the thermal envelope, treatment of thermal bridges, airtightness, ventilation, solar control, and moisture behaviour are not considered together.

This study provided a structured analytical review and criterion-based qualitative synthesis of the principal retrofit measures relevant to existing masonry buildings. The assessment considered their relative contribution to energy efficiency, thermal comfort, indoor air quality, moisture protection, and building durability. The results indicate that continuous insulation and thermal bridge reduction have a particularly broad influence on building performance, while airtightness and mechanical ventilation with heat recovery form a complementary system for reducing uncontrolled energy losses and maintaining controlled indoor air conditions. High-performance windows and doors, solar control, and daylight utilization must be coordinated according to orientation and climatic conditions.

The analysis further confirms that moisture management represents a cross-cutting requirement. Changes to insulation, thermal bridges, airtightness, and ventilation can modify the temperature and moisture conditions of existing masonry assemblies and influence their long-term durability. This is particularly important where internal insulation is applied because of façade or architectural restrictions.

The main contribution of the study is the development of a common analytical framework that enables the principal retrofit measures to be compared across multiple performance criteria. The framework highlights that the effectiveness of a retrofit strategy depends on the interaction between measures rather than on the isolated performance of individual components.

Finally, the findings indicate that the full Passive House standard may not be technically feasible for every existing masonry building. Building-specific structural, architectural, hygrothermal, spatial, and economic constraints must therefore be considered when defining retrofit targets. Nevertheless, substantial improvements in energy performance and indoor environmental quality can be achieved through the systematic and coordinated application of Passive House principles. Where full compliance is not feasible, an EnerPHit-oriented approach may provide an appropriate strategy for adapting high-performance renovation principles to the specific limitations of the existing building.

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