Sustainable Retrofitting of Heritage Buildings: Conservation-Compatible Energy Efficiency Strategies Through Systematic Evidence Synthesis

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Abstract — **Historic buildings make up around 30% of the European building stock but use 40% more energy than modern buildings of the same type, thus posing a major challenge to sustainability. This systematic review of 12 peer-reviewed studies (2011-2025) confirms that energy-saving retrofits compatible with the buildings original function result in 50-70% reduction of the energy used for daily operational activities while the heritage values are preserved. The four international case studies (Greece, Slovakia, Italy, China) demonstrate the technic al feasibility in a variety of contexts: Kaisariani social housing (Athens) lowered its primary energy consumption by 97%; rammed earth buildings (China) achieved a 72% reduction with payback periods of 10 years. EN 16883:2017 standard sets out a universal five-stage assessment process combining heritage preservation principles (minimum intervention, reversibility, compatibility) with energy performance requirements (EPBD 2018/844/EU, nZEB standards). The main findings: moderate retrofit measures (50-70% reduction) are realizable in 70% of the projects; deep retrofits (70-90%) in 20%; nZEB possible in 10-15% with extensive intervention. Economic feasibility was demonstrated by the nine to 12 years payback periods across the case studies. The obstacles to the implementation (cost premiums, lack of skills among professionals, regulatory conflicts) can be overcome by heritage-specific incentives, integrated training programs, and simplified local regulations. There is no doubt that, on the one hand, saving energy and, on the other hand, conserving the architectural heritage are not contradictory goals but, in fact, complement each other if the application of systematic interdisciplinary methodologies is ensured. This paper offers a comprehensive evidence synthesis, validated retrofit strategies, comparative case study analysis, and evidence-based policy recommendations for stakeholders.**

Index Terms—**Heritage buildings, energy retrofitting, conservation-compatible design, EN 16883:2017, nearly zero-energy buildings (nZEB), Building Integrated Photovoltaic (BIPV) systems, embodied carbon, sustainable retrofit strategies, lifecycle assessment, regulatory frameworks**

I. INTRODUCTION

Historic buildings constitute about 30% of the European building stock and, at the same time, they are the main source of cultural preservation, as they consume on average 40% more energy than modern buildings . The building sector is responsible for 40% of the total energy consumption in the European Union and 36% of carbon dioxide emissions. Within this sector, heritage buildings require special attention because of their combined low thermal performance and high cultural value . The retrofitting problem stems from the preservation of heritage being, in essence, a minimum intervention, authenticity of materials, and reversibility of the changes, while on the other hand, energy performance regulations require nearly Zero-Energy Building (nZEB) standards to be met mainly by envelope improvements and integration of renewable energy . This contradiction has historically led heritage buildings to be granted exemptions from energy efficiency requirements, thus continuing their energy inefficiency without addressing the concerns of both sustainability and preservation. The recent European regulatory changes mainly the EPBD Recast 2018/844/EU and the EN 16883:2017 standard have led to the understanding that energy conservation compatible with the heritage can be carried out if the systematic, evidence-based methodology is used .

Table 1 shows the quantitative data of the regional distribution of heritage buildings:

Heritage Building Stock Distribution by Region and Conservation Status

Region	Heritage Stock	% of Total	Conservation Status
United Kingdom	~400,000 listed	30-40%	Formal statutory protection
European	22.69%	22.69%	Variable by

Region	Heritage Stock	% of Total	Conservation Status
Union	pre-1945		jurisdiction
Slovakia	14.38% pre-1945	14.38%	Protected historic reserves
Italy	~37,000 listed	15-20%	High statutory protection

Source: [1][3][4][6]

This systematic review addresses three research questions:

1. RQ1: To what extent do conservation-compatible retrofits achieve operational energy reduction while preserving heritage values?
2. RQ2: What retrofit technologies and methodologies prove most effective across diverse building types and geographies?
3. RQ3: What policy frameworks, financial mechanisms, and implementation strategies enable scaling heritage retrofitting?

This paper synthesizes evidence from 12 peer-reviewed sources documenting quantitative retrofit outcomes, regulatory frameworks, case studies across international contexts, and implementation pathways. The findings demonstrate that heritage preservation and energy efficiency constitute complementary rather than contradictory sustainability objectives.

II. LITERATURE REVIEW

A. Regulatory Framework Evolution

The European Union has progressively tightened building energy performance requirements through the successive directives, most notably EPBD Recast 2018/844/EU. Major renovations of buildings larger than 250 m2 are required to have very high energy performance. The directive specifies the minimum energy efficiency requirements for retrofitted buildings and mandates long-term building renovation strategies that will enable the decarbonization of the building stock by 2050. Nearly Zero-Energy Building (nZEB) standards define that buildings should have a very high energy performance [with] nearly zero or very low amount of energy required... covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby. The implementation is mandatory for all new public buildings that must achieve nZEB standards by 2019, and all major renovations by 2021, with some derogations for historic properties. EN 16883:2017 Conservation of Cultural Heritage Guidelines for Improving the Energy Performance of Historic Buildings offers a framework across Europe specifically for heritage building retrofits. It recognizes that well-balanced retrofit solutions can exist and can be evaluated case-by-case through detailed assessment criteria, thus providing a systematic methodology for simultaneously evaluating heritage preservation and energy efficiency goals. The standard has been instrumental in practitioners' ability to reconcile potentially conflicting regulatory requirements.

B. Heritage Conservation Principles

International heritage conservation is based on a framework of principles that are clearly defined:

Venice Charter (1964): It is the very first document that sets up the fundamental idea, namely that in every possible way, the understanding of the significant parts of the past should be made easier by making them understandable in the present."

ICOMOS Charter for Restoration (1990): This document offers principles for "the analysis, conservation and structural restoration of architectural heritage" and makes the point that restoration should be done with scientific rigor and respect for the materials already existing".

Conservation Principles Key Concepts:

Minimum Intervention: The changes should be kept at the minimum level that is absolutely necessary to achieve the functional and conservation objectives

Reversibility: In cases where this is possible, interventions should be reversible or removable without taking away or permanently changing the original material

Compatibility: The new interventions must be in harmony with the historical character of the building, the materials, and the construction techniques

Authenticity and Integrity: The cultural significance of the building should be ensured through the preservation of the original materials, the historical proportions, the character-defining features, and the symbolic meanings

When these principles are combined with the structured EN 16883:2017 method in a systematic manner, they become an effective tool for implementing energy-saving measures that do not damage but rather conserve the heritage values.

C. Retrofit Challenge Synthesis

Panakaduwa et al. (2024) performed a systematic literature review of 52 peer-reviewed papers addressing heritage building retrofit challenges and identified nine major challenge categories that influence the feasibility and the results of the retrofit.
The challenges that have been cited the most include:
balancing heritage values with energy efficiency standards, complexity of retrofit works accommodating non-standard construction methods, cost premiums (2040% above modern building retrofits), and limited availability of professionals trained in both heritage preservation and modern energy efficiency techniques.

Buda et al. (2021) through case study analysis showed that conservation-compatible retrofit solutions can be technically achieved across different building types if systematic interdisciplinary methodologies are applied. The main insight: the seeming contradiction between conservation and energy efficiency is resolved by careful design, material selection, and phased implementation strategies.

D. International Case Study Evidence

Mediterranean Social Housing (Kaisariani, Athens):
Kanetaki et al. (2025) provided a detailed account of the renovation of a refugee housing complex from the 1920s that not only physically but also symbolically represented the memory and the culture of the displaced Greek populations. The refitting approach leaned heavily on internal insulation (vapor-permeable materials), mechanical ventilation with heat recovery (MVHR), heating systems upgrades, and the deliberate solar thermal and photovoltaic systems installation. The output showed a 97% reduction in primary energy consumption while the outward appearance and the community identity remained intact. The project has been achieving a payback period of roughly 10 years mainly through the energy bill savings and the incentive programs.

Historic Urban Structures (Bratislava, Slovakia):

Hubinsk et al. (2023) performed an exhaustive study on the potential of Building Integrated Photovoltaic (BIPV) installation across 17 historic structures in the protected Monument Reserve. Coupling 3D morphological modeling, solar irradiation analysis, and visual impact assessment, the researchers pinpointed the places attaining 2040% of the annual renewable electricity generation with very slight heritage impact. The principal discovery was the negative correlation between the total building size and the energy self-sufficiency ratio-the smaller historic buildings are frequently the ones reaching a positive energy balance (generating more than consuming annually).

Listed Building Energy Transition (Genoa, Italy):

Franco & Mauri (2024) described a detailed heritage building retrofit that reached near zero energy building (nZEB) parameters, while complying with Italian Ministerial Decree requirements . The team of professionals from different disciplines such as conservation architects, structural engineers, building physicists, and energy engineers followed a thorough method based on EN 16883:2017. The retrofit measures were an internal insulation with vapor-permeable materials, high-performance windows in original profiles, modern HVAC systems with minimal spatial impact, and strategic renewable energy integration. The building has been estimated to reduce around 70% of its operational energy with a 9-year payback period.

Vernacular Architecture Retrofit (Rammed Earth, China):

Jiang et al. (2022) implemented multi-objective optimization to evaluate 28 retrofit scenarios of traditional taipa (compacted earth) construction representing the vernacular of the past 1000 years . The optimization effort balanced three competing objectives: energy savings, carbon reduction, and economic viability. The optimal solution chosen was: expanded polystyrene (EPS) internal insulation (50 mm thickness) combined with polyurethane windows (80-series, low-E coating). The outcomes: 72% energy reduction, 50% greenhouse gas reduction, 10-year payback period, and exterior rammed earth look fully preserved.

E. Technological Solutions and Innovations

Polo Lpez et al. (2021) created a comprehensive framework for evaluating the risks and benefits of integrating Building Integrated Photovoltaics (BIPV) into historic properties. Their framework considers the visual impact, technical feasibility, heritage significance, economic viability, and environmental performance of the integration through a multi-dimensional evaluation.

Mahmad et al. (2024) identified considerable policy gaps in the area of embodied carbon assessment for heritage conservation decision-making. They pointed out that in material selection for which the lifecycle carbon emissions are often neglected, even though the manufacturing, transportation, and installation carbon emissions for the retrofit are already accounted for, and are recognized as significant.

III. METHODOLOGY

A. Literature Review Framework

This systematic review adhered to the PRISMA guidelines to ensure transparency and reproducibility. The literature search was performed on Scopus, Web of Science, and Google Scholar databases using the following keywords: "heritage building retrofit", "conservation-compatible energy efficiency", "EN 16883:2017", "historic building nZEB", "BIPV heritage", "vernacular architecture retrofit".

B. Selection Criteria

Inclusion Criteria:

1. Peer-reviewed journal articles, technical reports, or conference proceedings
2. Published 2011-2025 (capturing EN 16883:2017 implementation and recent innovations)
3. Quantitative energy performance data from heritage building retrofits
4. Focus on conservation principles and heritage preservation compatibility
5. International case studies or systematic methodologies

Exclusion Criteria:

1. Non-peer-reviewed articles or opinion pieces
2. Studies lacking quantitative retrofit outcome data
3. New construction buildings (not retrofits)
4. Studies not addressing heritage conservation compatibility

C. Data Extraction and Analysis

They looked at the data they got. It included things like how much energy was saved how long it took to get their money back how much things cost, ways to preserve old buildings what they did to fix up old buildings what the buildings were like and the rules that applied. They put all the data into charts so they could compare things and see what was the same in each case. The data had things like energy reduction percentages, payback periods, in years cost data, heritage preservation strategies, retrofit measures they used building characteristics and the policy and regulatory context.

We look at the Energy reduction in different case studies. Compare them. The Energy reduction is shown as a percentage and we also look at how it takes to get our money back. We set targets for how the buildings should perform after we fix them up. These targets are based on how work we do, to the buildings, which can be a little a medium amount, a lot or a complete renovation to make them nearly zero energy buildings. We then try to figure out if it's possible to reach these targets and make the buildings perform at the desired level.

Qualitative Synthesis: Retrofit strategies and heritage preservation approaches compared for common themes; implementation barriers and solutions identified; policy frameworks analyzed for enabling conditions.

Multi-Objective Evaluation: Cases analyzed across four sustainability dimensions: environmental (energy/carbon), economic (cost/payback), social (community impact), cultural (heritage preservation).

IV. RESULTS AND DISCUSSION

A. Case Study Performance Outcomes

Four international case studies demonstrate retrofit feasibility across diverse contexts:

International Heritage Building Retrofit Case Studies: Comparative Performance Outcomes

Project	Primary Energy Reduction	Heating Load Reduction	Payback Period	Heritage Strategy
Kaisariani (Greece)	97%	63–76%	10 yrs	Internal insulation
Bratislava (Slovakia)	20–40% BIPV	25–35%	7–12 yrs	Strategic placement
Genoa (Italy)	70% operational	65%	9 yrs	Conservation principles
Rammed Earth (China)	72%	72%	10 yrs	Exterior preservation

Source: [1][4][6][10]

Analysis reveals consistent achievement of 70–97% energy reduction across case studies, with payback periods clustering around 9–12 years. Notably, heritage preservation strategies vary by context but consistently prove compatible with substantial energy improvements.

B. Retrofit Technology Performance Matrix

Retrofit Measure Performance: Energy Impact, Heritage Compatibility, and Cost

Retrofit Measure	Energy Reduction	Heritage Compat.	Cost	Implementation
Attic Insulation	15–25%	Excellent	Low	Easy, phased
Internal Wall Insulation	20–35%	Good	Medium	Labor-intensive
Historic-Profile Windows	10–20%	Excellent	High	Custom fabrication
Air Source Heat Pump	15–25%	Good	Medium	Moderate coordination
MVHR Systems	5–10% + moisture	Good	Medium	Integration needed
BIPV Systems	20–40%	Medium	High	Visible commitment
Solar Thermal	5–15% DHW	Good	Medium	HVAC integration
Secondary Glazing	10–20%	Excellent	Medium	Reversible

Source: [3][5][7][12]

Table 2 demonstrates that conservative measures (attic insulation, secondary glazing) achieve excellent heritage compatibility with modest energy gains; moderate measures (internal insulation, heat pumps) balance performance and compatibility; comprehensive measures (BIPV, extensive envelope work) maximize energy reduction with increased heritage considerations.

C. Realistic Performance Targets

Heritage Building Retrofit Energy Performance Distribution: Targets and Project Feasibility

Retrofit Type	Target Reduction	Project Frequency	Heritage Impact	Typical Cost
Conservative	30–50%	15%	Minimal	Low
Moderate	50–70%	70%	Medium	Medium
Comprehensive	70–90%	20%	Medium-High	High
nZEB Approach	90–100%	5–10%	High	Very High

Source: [1][3][10]

Analysis across 12 peer-reviewed sources reveals that moderate retrofits (50–70% reduction) represent optimal balance point: substantial energy savings, reasonable cost justifying 10-year payback, achievable in 70% of heritage buildings while preserving character. Comprehensive retrofits (70–90%) feasible in approximately 20% of projects. nZEB achievement requires intensive intervention in only 5–15% of buildings with optimal conditions (small buildings, minimal shading, owner commitment).

D. EN 16883:2017 Assessment Framework

EN 16883:2017 Five-Phase Systematic Assessment Methodology for Heritage Building Retrofit

Phase	Objective	Key Deliverables	Duration
1. Historical Analysis	Document heritage significance	Heritage values matrix	4–8 wks
2. Performance Diagnosis	Establish baseline conditions	Energy audit, thermal imaging	4–6 wks
3. Solution Definition	Identify compatible options	3–5 retrofit scenarios	4–8 wks
4. Detailed Analysis	Quantify performance	Energy models, LCA, financials	6–10 wks
5. Decision-Making	Select optimal strategy	Implementation plan	2–4 wks

Source: [3][6]

EN 16883:2017 methodology proves essential enabling rigorous simultaneous evaluation of heritage preservation and energy efficiency objectives. Five-phase structure ensures comprehensive assessment of building significance, current performance, retrofit options, and implementation pathways.

E. Implementation Barriers and Solutions

Major Implementation Barriers: Evidence-Based Solutions and Effectiveness

Barrier	Severity	Solutions	Status
Cost Premium (20–40%)	High	Heritage incentives, phased work	Proven
Professional Skills Gap	High	Training programs, IPD models	Emerging
Regulatory Conflicts	Medium	EN 16883:2017, streamlined permits	Improving
Community Resistance	Medium	Engagement, transparent communication	Essential
Embodied Carbon Gaps	Medium	LCA requirements, guidance documents	Needed
Performance Data Gap	Medium	Extended monitoring (10–20 years)	Critical

Source: [5][9][12]

Analysis identifies cost premiums as highest-severity barrier, addressable through heritage-specific financial incentives recognizing that historic buildings require 20–40% higher retrofit costs. Professional capacity gaps require systematic investment in university curricula, continuing education, and mentorship programs. Regulatory conflicts resolvable through integrated standards and streamlined permitting processes.

F. Discussion

Heritage preservation and energy efficiency are things that actually work together. The facts show that heritage preservation and energy efficiency are not opposing goals. Rather they complement each other when it comes to sustainability. There are four examples from around the world where they were able to reduce energy use by 70 to 97 percent while still keeping the heritage values intact which proves it is technically possible. The rules set out in EN 16883:2017 give us a tried and tested framework that allows us to achieve both heritage preservation and energy efficiency at the time which is really important, for heritage preservation and energy efficiency. Heritage preservation and energy efficiency are both crucial.

Moderate retrofits are the way to go. They can cut energy use by fifty to seventy percent. This is a balance because it reduces the amount of carbon used a lot does not cost too much and most old buildings can still look the same. We can do this kind of retrofit to seventy percent of old buildings.

That means we can do it to a lot of buildings and it will make a difference. Moderate retrofits are a choice because they can pay for themselves in about ten years.

Economic Viability Confirmation: Heritage retrofitting is an idea because it saves you money in the long run. It takes around 9 to 12 years to get your money but it works for many different types of buildings. When you look at how much a building costs over 30 to 50 years you will see that retrofitting saves you a lot of money on energy bills. This makes it a good investment, for people who do not have a lot of money to spend as long as they get some help with the costs. Heritage retrofitting is a thing to do because it helps you save money and it is good, for the building.

When we talk about Policy Framework Integration we need to make sure that all the rules and laws are working together. This is really important for retrofitting. We have to make sure that heritage conservation regulations and building energy codes and environmental standards and renewable energy requirements are all aligned.

There are some rules and guidelines that can help us with this, like the standard EN 16883:2017 and the EPBD Recast 2018/844/EU. Some countries are also coming up with their guidance.. To actually make this work we need to adapt these rules to each specific area and make the decision-making process easier and faster for Policy Framework Integration.

Knowledge Dissemination Gap: Despite substantial technical feasibility demonstrated through case studies and peer-reviewed research, widespread awareness remains limited among building owners, practitioners, and policy makers. Case study documentation, professional training programs, and accessible guidance materials essential for scaling retrofit rates to meet climate targets.

V. CONCLUSION

This review looks at twelve studies that were checked by experts. It shows that making old buildings energy efficient can be done without hurting their significance. The main points are:

1. We have shown that it is technically possible: four case studies from around the world show that we can cut energy use by 50 to 97 percent in types of buildings, locations and cultures. If we make some changes, to buildings like fixing the windows and adding insulation we can cut energy use by 50 to 70 percent in about 70 percent of these buildings. If we make changes we can cut energy use by 70 to 90 percent in about 20 percent of these buildings.. If we really work hard at it we can cut energy use almost completely to nearly zero in about 10 to 15 percent of these buildings which is what we call a nearly zero energy building or nZEB.

2. We looked at the money side of things. It is a good idea. If we spend money to fix up buildings we will get that money back, in 9 to 12 years. This is an investment because it saves us a lot of money over the long term. Like 30 to 50 years, which is how long buildings usually last. Retrofit investments are a way to go because they save us money in the long run.

3. There are some methods we can use to do things in a way. The European Standard, EN 16883:2017 has an useful framework. This framework has five phases that help people make decisions. These decisions are about how to preserve buildings and also make them energy efficient. The framework is based on facts. It helps practitioners make choices that work for both heritage preservation and energy efficiency. The European Standard EN 16883:2017 is really helpful, for people who work with buildings and want to make them energy efficient.

4. We can deal with the problems that stop us from implementing something. These problems are the cost not having people with the right skills and rules that do not work well together. We found these problems by looking at what other people have written. We can solve these problems with money help for heritage projects training, for professionals that covers everything they need to know and making the rules simpler and easier to follow. This way heritage projects can get the help they need with money people can get the training they need. The rules will not be confusing. Heritage projects will get heritage- financial incentives professionals will get integrated professional training and we will have streamlined regulatory frameworks.

5. Policy Pathways are Clear: We have rules like EPBD 2018/844/EU and EN 16883:2017 that give us a foundation for Policy Pathways. To make

Policy Pathways work we need to create policies that're specific to each area. These policies for Policy Pathways should include standards for energy performance that fit with buildings ways to help people pay for changes training for professionals and ways to share knowledge, about Policy Pathways.

6. Heritage Preservation and Energy Efficiency are Complementary: Evidence unambiguous: heritage preservation and energy efficiency constitute complementary sustainability objectives when systematic interdisciplinary methodologies applied. This reframing moves discussion from defensive preservation seeking exemptions toward proactive retrofitting demonstrating compatibility.

A. Future Research Directions

1. Extended Performance Monitoring: Long-term studies (10–20 years) documenting actual energy performance versus design predictions, occupant comfort outcomes, and material durability in retrofitted heritage buildings.

2. Hygrothermal Performance Validation: In-situ testing and computational modeling of moisture behavior in retrofitted buildings, particularly addressing internal insulation in historic buildings with hygric-sensitive construction.

3. Social Impact Assessment: Systematic evaluation of retrofit impacts on community identity, energy affordability, social housing stability, and place attachment in socially significant heritage buildings.

4. Embodied Carbon Policy Integration: Development of heritage-specific lifecycle carbon assessment frameworks and guidance on low-embodied-carbon material selection for historic retrofits.

5. Professional Training Program Evaluation: Assessment of heritage retrofit professional training effectiveness and career pathway development in architecture, engineering, and construction sectors.

B. Practical Recommendations

For Building Owners: You should get an energy check done by experts who know how to work with old buildings. These experts should include people who specialize in preserving buildings engineers who understand energy and physicists who know about buildings. They should follow a method to plan the work, which is explained in something called EN 16883:2017. This method helps make a plan for fixing up the building in a way that makes sense.
You can do the work in steps. Use the money you save from the first step to pay for the next one. It is an idea to write down what you do and what happens so other people can learn from your experience, with heritage building retrofitting and energy audits.

For Policy Makers: Develop heritage-specific energy performance standards establishing tiered targets (30–50% conservative, 50–70% moderate, 70–90% comprehensive, 90

For Researchers and Academics: Conduct extended performance monitoring of retrofitted buildings over 10–20 year periods; document diverse case studies enabling cross-context learning; investigate hygrothermal and structural performance of novel retrofit approaches; assess social and cultural dimensions of retrofitting; develop accessible case study databases and guidance materials for practitioner use.

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