Interreg CENTRAL EUROPE

Co-funded by the European Union

ZEB4ZEN

ZEB4ZEN

D.3.1.3. Strategy on energy retrofit of cultural heritage neighbourhoods

VERSION 1 (REVISED OCTOBER 2026)
01 2026



D.3.1.3. Strategy on energy retrofit of cultural heritage neighbourhoods 0

Strategy on energy retrofit of cultural heritage neighbourhoods 4

A. INTRODUCTION 4

B. STARTING POINT, REGULATIONS AND GUIDELINES 5

1. REGULATORY FRAMEWORK 7

1.1. Croatia 7

1.1.1. General Legal Framework for Building Renovation in Croatia 7

1.1.2. Renovation of Existing Buildings – General Rules in Croatia 7

1.1.3. Specific Regime for Cultural Heritage Buildings in Croatia 8

1.1.4. NECP Update and National Building Renovation Plan (NPOZ) – Policies and Plans Relevant to Renovation and Heritage in Croatia 9

1.1.5. Programmes and Guidance for the Energy Renovation of Cultural Heritage Buildings 9

1.1.6. Heritage energy retrofits in Croatia 11

1.1.7. Conclusion 13

1.2. Italy 15

1.3. Germany 18

1.4. Poland 21

1.4.1. Heritage Conservation Laws and Authorities in Poland 23

1.4.2. Balancing Energy Efficiency with Heritage Preservation 24

1.4.3. Heritage energy retrofits in Zamość 27

1.4.4. Conclusions 30

C. PROCEDURE FOR IMPLEMENTING ENERGY RENOVATION OF BUILDINGS WITH THE STATUS OF CULTURAL PROPERTY 31

1. Neighbourhood definition and boundary setting 31

2. Project documentation 34

3. Specifics of project documentation preparation 35

D. ENERGY EFFICIENCY MEASURES ON BUILDINGS WITH THE STATUS OF CULTURAL PROPERTY 36

1. Moisture rehabilitation as a prerequisite for energy/comprehensive renovation 36

1.1. Sources and Mechanisms of Moisture in Historic Buildings 36
1.2. Why Moisture Control Must Precede Insulation 39
1.3. Compatible Methods of Moisture Rehabilitation for Protected Buildings 40
1.4. Recommended Sequence of Intervention 44
2. Increasing the thermal protection of the heated space envelope 47
3. Improving the energy efficiency of existing or installing new technical systems in a building 48
3.1. Heating and Domestic Hot Water (DHW) Systems 49
3.2. Cooling Systems 50
3.3. Ventilation Systems 50
3.4. Lighting Systems 50
3.5. Renewable Energy Sources (RES) in Technical Systems 51
E. RECAPITULATION OF THE COMBINATION OF MEASURES TO INCREASE ENERGY EFFICIENCY OF THE BUILDINGS 52
F. LESSONS FROM THE ZEB4ZEN PILOT NEIGHBOURHOODS 57
4. How the strategy was developed - tasks and inputs 57
5. Main challenges identified in the four pilot neighbourhoods 58
6. Influence of the technical and heritage assessments on the strategy 58
7. Lessons from the Zamość thermal renovation pilot 59
8. Lessons from the Karlovac green and digital energy investment 59
9. Experience from establishing the renewable energy community in Palmanova 60
10. Results from Quedlinburg relevant to heritage-sensitive energy planning 60
11. Overview: implemented results versus planned or proposed actions 61
12. Common recommendations derived from the pilot experiences 61
13. Differences between national regulatory frameworks and their implications for implementation 62
14. Respecting UNESCO World Heritage requirements 62
15. From heritage retrofit to zero-emission neighbourhoods 63
16. Practical steps for municipalities wishing to replicate the strategy 63

17. Tasks performed and partner contributions 63

18. Adoption and application of the strategy 64

G. CONCLUSION 64

Strategy on energy retrofit of cultural heritage neighbourhoods

A. INTRODUCTION

The transformation of historic city centres through energy retrofits demands more than local intervention—it calls for cross-border knowledge sharing, harmonized methodologies, and multi-stakeholder collaboration. Interreg programmes across Europe have become critical catalysts in this process. By funding pilot projects, facilitating partnerships among heritage and energy actors, and promoting transferable best practices, Interreg strengthens the capacity of regions to reconcile cultural preservation with climate goals.

One flagship example is the ZEB4ZEN (Zero Energy Buildings for Zero Energy Neighbourhoods) initiative under Interreg Central Europe. ZEB4ZEN develops a transnational methodology and local action plans for converting historic urban quarters into nearly zero-energy districts, while safeguarding their cultural and architectural integrity. Within its pilot actions, the city of Zamość has carried out heritage-compatible internal insulation and energy diagnostics of a protected building, in coordination with the conservation office and without altering the historic façades; Karlovac and Palmanova have implemented renewable-energy solutions adapted to heritage constraints, and Quedlinburg has developed a neighbourhood energy baseline and digital twin.

Another relevant effort is the **VIOLET (preserVe tradItiOnal buiLdings through Energy reducTion)** project under Interreg Europe, which targets traditional and heritage buildings across multiple regions. VIOLET links energy agencies with cultural heritage institutions to improve regional public policies, especially by strengthening alignment of energy regulation with heritage constraints[1,2].

In the Danube region, the **EE-Heritage** project exploits advanced digital and AI techniques to optimize energy management, maintenance, and comfort in heritage buildings. It aims to couple heritage protection with intelligent HVAC, shading, and adaptive control systems in a manner respectful of historic materials and interiors[3].

These projects underscore that heritage retrofit is inherently **interdisciplinary** and **multiscalar**:

- It brings together **architects, conservationists, engineers, data scientists, urban planners, and community stakeholders**.
- It combines **heritage assessment, energy modelling, material science, digital twins, and policy design**.
- It demands **spatial and neighbourhood-level thinking** (not just individual buildings), opening synergies through district heating, shared infrastructure, and integrated action plans. For the purposes of this strategy, a cultural heritage neighbourhood is understood as an urban ensemble: a spatially continuous group of protected and non-protected buildings, public spaces, infrastructures and users that together form one energy and heritage system. Energy retrofit in this context is not the sum of isolated building renovations, but a coordinated transformation of the neighbourhood's energy flows, technical systems, public space and governance structures.Accordingly, buildings are treated as components of a wider urban metabolism, where heat, electricity, mobility, water, public space and heritage values interact. The strategy therefore addresses not only building envelopes and systems, but also district-level solutions such as shared heating and cooling,

[1] https://projects2014-2020.interregeurope.eu/violet/

[2] https://www.interregeurope.eu/find-policy-solutions/stories/violet-adapts-regional-policies-for-heritage-buildings

[3] https://interreg-danube.eu/projects/ee-heritage

renewable energy clusters, coordinated phasing of works, and common rules for protected ensembles.

- It encourages **methodological transferability**: protocols, templates, and simulation frameworks developed in one city can be adapted elsewhere.

In this document, we build upon the lessons and tools emerging from ZEB4ZEN, VIOLET, and EE-Heritage, integrating them into a cohesive strategy for cultural-heritage neighbourhoods. Our aim is to provide a roadmap that is technically robust, culturally sensitive, and regionally replicable.

The strategy is explicitly derived from the experience gathered in the four ZEB4ZEN pilot neighbourhoods – Zamość (PL), Karlovac – Zvijezda (HR), Palmanova (IT) and Quedlinburg (DE). The chapter "Lessons from the ZEB4ZEN pilot neighbourhoods" presents the challenges identified in each pilot, the influence of the technical and heritage assessments on the strategy, the lessons from the pilot investments, common recommendations, the implications of the different national regulatory frameworks, practical replication steps for municipalities and a summary of the tasks performed and partner contributions. Throughout that chapter, results already implemented in the pilots are clearly distinguished from planned or proposed actions.

B. STARTING POINT, REGULATIONS AND GUIDELINES

The European *Energy Performance of Buildings Directive* (EPBD) sets the framework for improving the energy efficiency of buildings across the EU. The latest revision (EU/2024/1275) **entered into force 28 May 2024** and must be transposed by May 2026. The recast EPBD continues to require Member States to enforce minimum energy performance standards (e.g. nearly-zero energy buildings, NZEB) for new and existing buildings, as well as mandatory certification and inspections. Crucially, however, it **allows exemptions for historic and protected buildings**. EU guidance confirms that countries *"can exempt various categories of buildings from renovation requirements, including historical buildings"*[4], and heritage experts note that EPBD explicitly permits Member States to exclude listed monuments (or the parts being retrofitted) from strict performance rules. In practice, this means a balance must be struck: energy improvements should be sought wherever possible, but without impairing a building's cultural heritage value. For example, the EPBD mandates regular inspections of heating and cooling systems even for historic buildings, but permits alternative compliance routes (e.g. evaluating energy saving potentials rather than blindly replacing historic fabric).

Complementing the EPBD, the European standard **EN 16883:2017** ("*Conservation of cultural heritage - Guidelines for improving the energy performance of historic buildings*") provides a methodology for planning such retrofits. Published by CEN TC 346, it was developed by experts over six years. EN 16883 advocates a stepwise, multidisciplinary process: first thoroughly **characterize the building and its heritage constraints** (legal protections, aesthetic values, existing technical condition), then set energy-efficiency **goals** that respect those values, and finally evaluate all candidate measures in terms of their *benefit-risk* for the heritage fabric. Task 59 (IEA SHC) notes that EN 16883 "establishes a normative working procedure that planners and architects can use when retrofitting historic buildings". In practice, planners are urged to assess impacts of each measure on the historic character (e.g. whether interior insulation or new windows might risk damaging original materials or artwork) before proceeding[5]. In short, EN 16883 and related guidance promote **minimal intervention**: insulation and glazing upgrades are applied only when justified,

[4]https://energy.ec.europa.eu/topics/energy-efficiency/energy-performance-buildings/energy-performance-buildings-directive_en

[5] https://task59.iea-shc.org/article?NewsID=232

renewable systems are hidden or reversible, and routine maintenance (often the highest "hidden" efficiency gain) is emphasized[6,7].

Even with EU frameworks in place, a key challenge is the **interaction between national heritage laws and energy regulations**. Almost every country has a strict monuments-protection code requiring that restorations preserve authenticity (façades, materials, craftsmanship). These rules can appear to conflict with building-energy rules that demand envelope upgrades, solar installations, or thermal retrofits. Research shows this legal tension is common: many heritage statutes lack explicit provisions for energy retrofits, while building-energy laws often do not explicitly exempt protected monuments[8]. Conflicts typically arise over interventions like exterior insulation or new windows, which may alter the historic appearance. National systems attempt to harmonize these goals by allowing case-by-case exemptions and by requiring that any retrofit not "endanger, damage or destroy" the monument's values[9,10]. For instance, a recent analysis notes the absence of *automatic* retrofit requirements on heritage sites, instead stressing informed, expert-led decisions. The EPBD itself—and EN 16883—reflects this compromise: Member States may impose lower energy targets on monuments, or require only that *"at least 20%"* energy savings be achieved in a minimally invasive way[11][12]. In general, project teams are advised to "walk a fine line" between energy ambition and heritage impact, often favoring reversible or interior-focused solutions.

Neighbourhood dimension of the regulatory framework

Although energy and heritage regulations are formally applied to individual buildings (e.g. EPBD, EPCs, EN 16883), historic urban ensembles are legally and functionally managed as spatial units. Conservation zones, UNESCO buffer zones, protected cores and historic ensembles already operate at neighbourhood scale. ZEB4ZEN builds on this logic by aligning building-level compliance with neighbourhood-level planning and energy management.

This means that regulatory compliance (EPCs, conservation permits, technical standards) becomes an input to neighbourhood-level optimisation, rather than the final objective.

[6] https://heritagetribune.eu/europe/more-than-just-insulation-a-holistic-approach-to-energy-efficiency-in-historic-buildings/
[7] https://www.mdpi.com/2571-9408/4/4/215
[8] https://www.mdpi.com/2571-9408/4/4/194
[9] https://www.nt.sk/en/ochrana-a-obnova
[10] https://www.rehva.eu/rehva-journal/chapter/energy-retrofit-of-cultural-heritage-buildings
[11] https://www.renovate-europe.eu/wp-content/uploads/2018/09/Renovate2Recover-CROATIA.pdf
[12] https://www.renovate-europe.eu/wp-content/uploads/2018/09/Renovate2Recover-CROATIA.pdf

1. REGULATORY FRAMEWORK

Below we summarize each Central European country's regulatory framework and institutional setup for heritage retrofits, focusing on EPBD implementation, use of EN 16883, and the interface with heritage laws. We also note the key authorities responsible for approving and guiding renovations of protected buildings. Finally, representative examples or pilot initiatives are given to illustrate how these frameworks operate in practice.

1.1. Croatia

1.1.1. General Legal Framework for Building Renovation in Croatia

The Building Act is the overarching framework for all types of renovation – structural, functional and energy-related. It defines, among others, the concepts of a building, nearly zero-energy building (nZEB) and major renovation (renovation of more than 25% of the building envelope). Building owners must maintain buildings so that they meet basic requirements throughout their life cycle and gradually improve them, especially in terms of energy performance and accessibility.

The Energy Efficiency Act complements this by defining energy renovation as the implementation of energy-efficiency measures, including audits and certification, project documentation, improvement of the envelope and technical systems, use of renewables and building automation. For multi-apartment buildings, it also sets basic rules for how co-owners decide on and contract energy renovation.

The Technical Regulation on the Rational Use of Energy and Thermal Protection in Buildings specifies how energy performance requirements are met and demonstrated in design and reconstruction. It applies to new buildings and to reconstruction/major renovation, sets maximum U-values and limits for heat demand and primary energy, and requires that replacements of envelope parts or systems comply with these minimum performance levels.

A new Act on Energy Performance in Buildings is in preparation and is expected to consolidate provisions on energy performance, energy renovation, certification and decarbonisation of buildings, and to transpose the revised EPBD, including the pathway towards a zero-emission building stock and restrictions on public support for fossil-fuel boilers.

Taken together, these instruments provide the basic legal, institutional and technical framework for building renovation in Croatia.

1.1.2. Renovation of Existing Buildings – General Rules in Croatia

For existing buildings, the framework can be understood in three layers:

1. **Construction / building law**

The Building Act defines when renovation qualifies as major renovation, which interventions require a building permit and full project documentation, and the general obligations of owners. It also anchors the Long-Term Renovation Strategy and specific renovation programmes for different building categories.

2. **Energy-efficiency / policy**

The Energy Efficiency Act and the future Act on Energy Performance in Buildings regulate energy audits and certification, define energy renovation and provide the legal basis for national programmes for multi-apartment buildings, single-family houses and public buildings, implemented mainly via national funds and EU support.

3. **Technical / performance**

The Technical Regulation sets numerical targets (U-values, annual heat demand, primary energy) and the methodology and content of technical calculations and documentation. In cases of major renovation, designers must ensure that the renovated building meets minimum energy-performance requirements, and owners must maintain these performance levels in operation.

Energy performance certificates, which are mandatory in defined situations (sale, lease, certain renovations and public-sector buildings), are key tools for assessing the baseline, identifying measures and documenting achieved performance.

1.1.3. Specific Regime for Cultural Heritage Buildings in Croatia

Size and Characteristics of the Heritage Building Stock

The National Building Renovation Plan (NPOZ) provides the most comprehensive picture of cultural-heritage buildings in Croatia. It identifies:

- a very large number of buildings with protected status within urban and rural historic ensembles,
- additional individually protected public and residential buildings, and
- a substantial total useful floor area across public, multi-apartment and single-family buildings.

Due to age, construction techniques and location, a large share of these buildings belongs to the worst-performing segment of the stock targeted by MEPS. At the same time, strict conservation requirements limit permissible interventions on façades, roofs, windows and sometimes internal structures and systems, creating an inherent tension between energy and heritage objectives.

Exemptions from Minimum Energy Performance Standards and Criteria

NPOZ explicitly recognises that cultural-heritage buildings may be excluded from the group of buildings to which mandatory MEPS apply. In particular:

- Floor area of heritage buildings can be excluded from the calculation of the MEPS-covered stock.
- Exempt buildings are generally not eligible for instruments whose main purpose is to bring buildings up to MEPS (e.g. schemes focused on the worst-performing 16–26% of buildings).

Indicative exemption criteria include expected change of use, change in protection status, planned demolition, justified impossibility of implementation (e.g. serious financial distress) and unfavourable cost-optimality at building level.

At the same time, NPOZ stresses that, after 2030, the aim is to move towards deep renovation wherever feasible. For cultural-heritage buildings, it explicitly allows shallower renovation depths where full compliance with energy-performance requirements is technically, economically or functionally infeasible or incompatible with conservation. In practice, protected buildings are treated as a specific sub-category of the stock, for which MEPS obligations can be relaxed or waived, but at least partial energy renovation is encouraged.

Programme for the Energy Renovation of Cultural Heritage Buildings

The National Energy and Climate Plan (NECP) – Update introduces a dedicated measure for heritage buildings:

- ENU-6 – Programme for the Energy Renovation of Buildings with the Status of Cultural Heritage

ENU-6 is a separate financial programme running up to 2030 and targeted at:

- individually protected cultural monuments (buildings and complexes), and

- buildings located within protected cultural-historical ensembles.

The programme can support both integrated renovation (coordinated measures on envelope and systems) and packages of individual measures. It is expected to mobilise substantial investment, combining EU funds, the monument annuity and national/local budgets, and to deliver reduced heat demand, increased use of renewables and lower greenhouse-gas emissions in heritage buildings.

1.1.4. NECP Update and National Building Renovation Plan (NPOZ) – Policies and Plans Relevant to Renovation and Heritage in Croatia

The NECP Update positions the Long-Term Renovation Strategy for the National Building Stock by 2050 as the strategic backbone for renovation in Croatia. It aligns renovation objectives with climate and energy targets, aims to increase renovation rates and introduces indicators for the transition to nZEB and, ultimately, zero-emission buildings.

To implement these objectives in the building sector, NECP sets out a package of measures, including promotion of the "energy-efficiency-first" principle, renovation programmes for residential and public buildings, systematic energy management in the public sector, and measures addressing energy poverty and renewable energy in heating and cooling. Within this package, ENU-6 plays a key role in ensuring that protected buildings are included in the renovation wave while respecting conservation constraints.

NPOZ complements NECP by providing a more detailed building-sector perspective. It maps the building stock (including heritage), describes existing renovation policies, defines the concept and phased introduction of MEPS for the worst-performing part of the stock and sets out criteria and procedures for exemptions, with cultural-heritage buildings as the most prominent exempt category. It also identifies necessary legislative steps (new energy-efficiency laws, revision of technical regulations) to support implementation.

For heritage buildings, the combined effect of the NECP Update and NPOZ is that they are:

- explicitly recognised as a separate category within the building stock,
- eligible for exemptions from strict MEPS where justified,
- supported by a dedicated national programme (ENU-6), and
- allowed a shallower depth of renovation where conservation or cost-effectiveness constraints prevent full compliance, while still aiming to improve energy performance and reduce emissions as far as compatible with heritage protection.

1.1.5. Programmes and Guidance for the Energy Renovation of Cultural Heritage Buildings

Croatia has developed a specific set of programmes, recommendations and guidelines that define how energy renovation should be carried out on protected buildings and within historic urban ensembles so that climate and energy targets are met without compromising cultural value.

Programme for the Energy Renovation of Buildings with Cultural Heritage Status

The Programme for the Energy Renovation of Buildings that Have Cultural Heritage Status for the Period up to 2030 is the central strategic document for energy renovation of heritage buildings. It distinguishes:

- individually protected cultural properties, and
- buildings within protected cultural-historical ensembles.

The Programme defines different renovation approaches (from single energy-efficiency measures to more integrated packages), sets a minimum saving requirement for supported projects and provides an overview of the heritage building stock, barriers, financing concept and monitoring framework. In practice, it serves as the strategic umbrella under which grant schemes, technical guidelines and regulatory adjustments for heritage renovation are developed.

Recommendations on Energy-Efficiency Measures in Built Heritage

The Recommendations for the Application of Energy-Efficiency Measures in Built Heritage (Ministry of Culture) are an early horizontal tool to support renovation of historic buildings. They:

- explain how to assess and improve energy performance based on prior assessment of heritage values,
- promote a common approach for owners, designers, conservation services and funding bodies, and
- emphasise that energy renovation of heritage is desirable if measures are compatible with heritage values, reversible where possible and implemented in line with conservation procedures.

The Recommendations also clarify procedural aspects: the role of conservation authorities in issuing expert opinions, the need for planning information if fundamental building requirements or spatial-planning conditions are affected, and the possibility of derogations from technical rules under the Building Act where strict application would harm heritage values.

Guidelines for the Energy Renovation of Buildings with Cultural Heritage Status

The Guidelines for the Energy Renovation of Buildings with Cultural Heritage Status (2023), issued jointly by the Ministry of Culture and Media and the Ministry of Physical Planning, Construction and State Assets, operationalise the 2030 Programme and the Recovery and Resilience Plan. They are closely aligned with EU policy (European Green Deal, Renovation Wave, revised EPBD, EED, RED, etc.) and frame heritage renovation as part of the trajectory towards climate neutrality by 2050.

Key features include:

- an integrated, interdisciplinary approach, requiring coordinated work of architects, structural, mechanical and electrical engineers, with attention to building physics and multiple performance dimensions (energy, seismic safety, fire protection, indoor environment, accessibility, sustainability);
- a stepwise process for project preparation and permitting, grounded in conservation studies and heritage value assessments; and
- a catalogue of acceptable measures, covering moisture control, thermal upgrading of the envelope, improvement or replacement of technical systems, water-saving measures and green infrastructure, including examples of good practice.

Overall, these Guidelines are the main technical reference for designers and authorities when implementing energy renovation in heritage buildings.

Conservation Guidelines for Public Space and Installations in Historic Urban Areas

The General Conservation Guidelines for the Management of Public Space in Historic Urban Ensembles focus on the urban context – streets, squares and public spaces within protected cores. They highlight the large number of protected historic cores and building units and the system of zonal protection (zones A, B, C) embedded in spatial-planning documents.

The Guidelines identify key risks to historic character (visual clutter from advertising and temporary structures, poorly sited technical installations, growing tourism pressure) and call for systemic regulation through municipal decisions on communal order, in close cooperation with conservation departments. They provide specific rules for the siting and design of advertisements, terraces, technical installations and event

infrastructure, with emphasis on reversibility, minimal visual impact and protection of historic materials and views.

For energy renovation, these Guidelines are particularly relevant when planning external installations (e.g. heat-pump units, PV panels, shading devices) and when reconfiguring public space around renovated heritage buildings.

Practical Implications for Renovation Projects

Taken together, the Programme, Recommendations, energy-renovation Guidelines and public-space conservation Guidelines form a coherent framework for heritage-sensitive renovation in Croatia:

Strategic level: the 2030 Programme defines the scale of the task, categories of buildings, minimum savings and the overall financial and institutional model.

Procedural level: the Recommendations explain how to balance energy-efficiency requirements and heritage protection, including possible derogations from standard technical rules.

Technical level: the 2023 Guidelines provide detailed, interdisciplinary design guidance and a catalogue of measures compatible with conservation.

Urban context: the public-space Guidelines ensure that individual renovations do not undermine the character of historic ensembles.

For project promoters and public authorities, this means that energy renovation of cultural-heritage buildings should:

- start from a heritage value assessment and conservation study,
- be planned through an interdisciplinary design process,
- follow the specific procedural steps and approvals required by heritage and construction law, and
- align with the programme and guidance framework described above, so that cultural heritage becomes an active and visible component of Croatia's green transition.

1.1.6. Heritage energy retrofits in Croatia

Here are four illustrative Croatian case studies from the guidebook from 2013, showing how energy efficiency can be improved in protected buildings without compromising their heritage value. They include public and educational buildings in Varaždin, Zagreb and Pula, and demonstrate a range of compatible interventions – from window and roof upgrades to heating-system optimisation and low-cost control measures.

1. **Music School in Varaždin (protected cultural monument)**

The mid-18th-century Music School in Varaždin is a listed cultural heritage building that was fully reconstructed in 1999–2002. An energy audit identified poor thermal performance of the existing single glazing in otherwise preserved wooden windows. Because of heritage requirements, the frames had to be kept and only the glass changed to insulating glazing with a low U-value.



Figure 1 Music School in Varaždin, Croatia

The measure was expected to reduce thermal energy use for heating by around 28% with a simple payback of 7,5 years. This case illustrates how relatively non-intrusive glazing upgrades can deliver substantial savings without altering the historic appearance.

2. **City Palace Dverce, Zagreb (historic palace used for public administration)**

City Palace Dverce is a 19th-century representative building in Zagreb, used for protocol and administrative functions. The audit showed very high specific heat consumption and no insulation in the ceilings under unheated attic spaces and flat roofs. To preserve the facade, thermal insulation is added from the inside: 15 cm of insulation is placed above ceilings under unheated spaces, improving the U-value and reducing transmission losses.



Figure 2 City Palace Dverce, Zagreb, Croatia

The measure yields an estimated 22% reduction in heating energy, with a relatively modest investment and a payback time of about 2,6 years, demonstrating that “invisible” internal measures can be both heritage-compatible and cost-effective.

3. **First High School Varaždin (historic school building)**

The First High School in Varaždin consists of an older part from 1870 (adapted in 2002) and a newer wing from 2009. The old part suffers from roof leakage and inadequate thermal protection, threatening both the structure and energy performance. The proposed measure is a comprehensive roof reconstruction: preparing the substrate, installing vapour and permeable membranes, adding 15 cm of mineral wool, and replacing the complete roofing structure on about 1,800 m².



Figure 3 The First High School, Varaždin, Croatia

This intervention addresses urgent conservation needs (water ingress) while improving the thermal envelope, resulting in an estimated 10% reduction in heating energy. Although the investment is relatively high with a longer payback (25 years), it combines structural protection of a heritage school with measurable energy savings.

4. **Palace of Justice, Pula (heritage courthouse)**

The Palace of Justice in Pula is a 19th-century heritage building of about 4,300 m² serving as a courthouse. An energy audit identified several low- and medium-cost measures that do not interfere with its architectural value. The main proposal is to reconfigure the heating system in the attic, which currently relies on separate electric radiators, and to integrate it more efficiently with the central system, producing substantial financial (rather than energy) savings with a payback of about 7,5 years.



Figure 4 The Palace of Justice, Pula, Croatia

Additional measures include installing thermostatic radiator valves (roughly 10% fuel savings, payback under two years) and water-saving devices (payback around 1,3 years). The case underlines how audits in protected buildings can uncover quick-win operational and system improvements even when deep envelope interventions are constrained by conservation rules.

1.1.7. Conclusion

Croatia has put in place a relatively advanced and coherent framework for heritage renovation. Building, energy and technical regulations are complemented by a long-term renovation strategy, the NECP Update and NPOZ, which explicitly recognise cultural heritage as a distinct category of the building stock. Importantly, energy issues are now governed on two levels: the general Energy Efficiency Act and the forthcoming, more specific Act on Energy Performance in Buildings, which is designed to transpose the revised EPBD and steer the decarbonisation of the building stock, including heritage.

Through ENU-6 and the dedicated 2030 Programme, heritage buildings are not only granted some flexibility regarding MEPS, but also receive targeted financial and technical support. The Recommendations, technical Guidelines and public-space conservation Guidelines translate these strategic goals into practical design and

permitting principles. Overall, Croatia's approach shows that robust heritage protection can be combined with EPBD implementation and building-stock decarbonisation, provided that projects are value-based, interdisciplinary and aligned with this integrated policy and legislative framework.

References and sources:

- ***Building Act*** (Zakon o gradnju);
- ***Energy Efficiency Act*** (Zakon o energetskoj učinkovitosti);
- ***Technical Regulation on the Rational Use of Energy and Thermal Protection in Buildings*** (Tehnički propis o racionalnoj uporabi energije i toplinskoj zaštiti u zgradama);
- ***Draft Act on Energy Efficiency in Buildings 2025*** (Nacrt prijedloga Zakona o energetskoj učinkovitosti u zgradarstvu);
- ***Draft Act on Energy Efficiency 2025*** (Nacrt Zakona o energetskoj učinkovitosti);
- ***National Building Renovation Plan 2025 – NPOZ*** (Nacionalni plan obnove zgrada (NPOZ)
- ***Long-Term Strategy for the Renovation of the National Building Stock by 2050*** (Dugoročna strategija obnove nacionalnog fonda zgrada do 2050. godine);
- ***Update of the Integrated National Energy and Climate Plan of the Republic of Croatia for the Period 2021-2030*** (Ažuriranje integriranog nacionalnog energetskog i klimatskog plana Republike Hrvatske za razdoblje od 2021. do 2030. godine);
- ***Programme for the Energy Renovation of Buildings that Have Cultural Heritage Status for the Period up to 2030, 2022*** (Program energetske obnove zgrada koje imaju status kulturnog dobra za razdoblje do 2030. godine);
- ***Guidelines for the Energy Renovation of Buildings with Cultural Heritage Status, 2024*** (Smjernice za energetsku obnovu zgrada sa statusom kulturnog dobra);
- ***Recommendations for the Application of Energy Efficiency Measures in Built Heritage, 2019*** (Preporuke za primjenu mjera energetske učinkovitosti na graditeljskoj baštini);
- ***General Conservation Guidelines for the Management of Public Space in Historic Urban Ensembles,*** *2019* (Opće konzervatorske smjernice za upravljanje javnim prostorom kulturno-povijesnih cjelina gradskih obilježja).
- ***Efficiency and Energy Management in Cultural Heritage, Case Studies Guidebook, 2013*** *(Učinkovitost i upravljanje energijom u kulturnoj baštini, Priručnik s primjerima dobre prakse)*
- ***Photos:***
  - *https://varazdinski.net.hr/vijesti/kultura/63731/punih-190-godina-glazbena-skola-u-varazdinu-ostavila-snazan-trag-u-obrazovanju/*
  - *https://licegrada.hr/palaca-dverce-koju-je-1912-godine-kontesa-buratti-oporucno-ostavila-gradu-zagrebu/*
  - *https://varazdinski.net.hr/vijesti/skolski-kutak/129141/prva-gimnazija-domacin-susreta-najstarijih-hrvatskih-gimnazija/*
  - *https://www.glasistre.hr/pula/2024/10/14/-961328*

1.2. Italy

Italian energy saving policies began in 1976 with Law No. 373, which introduced the first regulations on the thermal insulation of buildings and the efficiency of heating systems.

The most important step came with Law No. 10/1991, which repealed the previous law and promoted the rational use of energy, the use of renewable sources and the division of the territory into climate zones.

After the Kyoto Protocol (1997), the EU approved Directive 2002/91/EC on the energy performance of buildings, which was transposed into Italian law by Legislative Decree 192/2005.

This decree — supplemented by subsequent measures such as Presidential Decree 59/2009 and Ministerial Decree 26/06/2009 — defines the criteria for the energy assessment and certification of energy performance of buildings and establishes the minimum requirements for new constructions and renovations.

Regions may adopt more restrictive rules. The regulations apply to public and private buildings, but buildings subject to the Cultural Heritage Code (Legislative Decree 42/2004) are subject to assessment by the Ministry of Culture, which decides on a case-by-case basis on compatibility with historical and artistic protection.

Legislative Decree 28/2011 transposes the European objectives on renewable energy and requires their integration into new or renovated buildings, with exceptions for cultural heritage.
The regulatory framework, which is constantly updated, represents a technical and cultural evolution towards sustainability:

- D.Lgs. 42/2004 (Codice dei beni culturali - Cultural Heritage Code)
- Legislative Decree 192/2005, the main national decree governing the calculation of the energy performance of buildings and the energy performance certificate (called APE), implementing the European directives;
- Legislative Decree 102/2014 on energy efficiency;
- Ministerial Decree of 26 June 2015 (Minimum Requirements 2015) defines the minimum requirements for new and renovated buildings, as well as the criteria for defining the energy class and designing nearly zero-energy buildings (nZEB);
- after Directive (EU) 2024/1275 Member States will have two years (until 29 May 2026) to transpose it into their respective legislative frameworks.

The UNI TS 11300 standard completes the system by providing technical criteria for calculating energy requirements and the use of renewable sources.

For works on listed buildings, it is necessary to contact the Superintendency and the Municipality to obtain the necessary authorisations.

- ### Guidelines for improving energy efficiency in cultural heritage

The “Guidelines for improving energy efficiency in cultural heritage - Architecture, historic and urban centres and districts” is a useful document issued by the Italian Ministry of Culture that provides recommendations for the assessment and improvement of the energy performance of protected cultural heritage, with reference to Italian regulations on energy saving and efficiency in buildings.

The Guidelines are intended for the management of protected cultural heritage, including the management of cultural heritage sites, museums, and other cultural institutions, and offer a comprehensive overview of strategies and methodologies for improving the energy performance of cultural heritage, while respecting its historical and architectural identity.

The Guidelines start from the regulatory framework and then suggests an analysis of the context through the study and understanding of architectural heritage, with particular attention to its protection, construction characteristics and environmental quality. It examines the regulatory framework of the Cultural Heritage Code, techniques for surveying and analysing historic buildings, and criteria for assessing and improving thermal, visual and acoustic comfort and air quality in historic and museum buildings. It also analyses building systems and their evolution, including modern and contemporary buildings, with a look at the latest materials and structures.

Then, the Guidelines focus on energy efficiency assessment for cultural heritage, addressing the issue of energy diagnosis and improvement in historic buildings, with the aim of reconciling the protection of cultural heritage with the needs of sustainability and energy saving. The first part introduces the concept of energy diagnosis, illustrating its purposes, levels of detail and operational phases, up to the particularities concerning listed buildings, where the margins for intervention are more delicate. The text then proposes a methodological procedure for improving energy efficiency, based on an integrated approach that starts from knowledge of the current situation and leads to the definition of interventions compatible with the historical and architectural values of the building.

The final part deals with the assessment of overall energy performance, with an analysis of the parameters and tools used to measure consumption and verify the effectiveness of renovation measures. The main technical and methodological issues are also discussed, such as the adaptation of regulations and calculation models to old buildings, which often do not meet contemporary standards.

Moving from theory to practice, the Guidelines provide a comprehensive overview of strategies and techniques for improving the energy efficiency of architectural heritage, integrating construction, plant engineering, technological, economic and management aspects. Its aim is to provide an operational guide to energy restoration, combining respect for history and materials with the need to reduce consumption, improve comfort and promote a more sustainable future for historic and modern buildings. The document explores strategies and technical solutions for improving the energy performance of historic buildings, while fully respecting their architectural and material values. It analyses interventions on the building envelope, illustrating methods and materials for thermal insulation, solar radiation control, humidity remediation and the improvement of walls, roofs and fixtures, always with a view to compatibility with restoration. An extensive section on technological systems explains how to optimise the production and use of thermal, cooling and electrical energy through efficient and minimally invasive systems, such as heat pumps and low-temperature systems.

The Guidelines then address lighting interventions and the integration of renewable sources — solar, biomass, geothermal — assessing their opportunities and limitations in relation to the landscape context and protection constraints. Space is also devoted to the economic analysis of interventions and the scheduled maintenance of systems, which are fundamental elements for ensuring efficiency over time. Finally, the volume opens up to the restoration of modern and contemporary buildings, proposing innovative design solutions that combine sustainability, technological innovation and the conservation of architectural heritage.

- ## Balancing energy efficiency with heritage preservation: good practices in Italy

In Italy, more than 200.000 buildings are listed as cultural assets: this provides many examples of balancing energy efficiency with heritage preservation and in this chapter two good practices of both public and privately owned listed buildings are presented.

Capodimonte Museum in Naples

In Naples, the Public-Private Partnership (PPP) was decisive for the restoration, redevelopment, energy efficiency and enhancement of the Capodimonte Museum.

In this case, the masterplan aimed at four goals: not only heritage protection, but also environmental, digital and social valorisation. An ecological and digital transition project is underway (works closure is expected in December 2025).

Responding to environmental and ecological needs, works started with the restoration of the architectural design of the historic French garden and the restoration of the sinuous lines of the English garden, the undergrowth, and other green areas of the 134-hectare complex with over 470 plant species. In 2017-18, marked by increased drought, a review of the irrigation system was initiated to develop the existing 18th-century system and maintain a green lawn for most of the year. The system allows the collection and reuse of rainwater, achieving an 80% water saving.

The Palace's roofs will be restored and upgraded with a photovoltaic system of over 500kWp, perfectly integrated into the historical context; 90% of electricity needed will be self-produced. The museum's air-conditioned areas will be increased from 8,000 to 14,500 square meters, with an advanced system for monitoring temperature, humidity, and air quality. 7,000 new light fixtures will be installed and 3,300 lamps will be replaced with LED technology for optimal lighting control.



Museo di Capodimonte – Source: Ministero della Cultura (Italian Ministry of Culture)

Casa Borghesan in Padua

The house dates back to 1927 and is a typical example of Art Nouveau architecture, with large windows, beautiful friezes, and moldings. The consistency of the perimeter followed the custom of the 1920s: three or four brick heads on the south side, on the public facade, and only two on the north side. The spacious, colorful rooms and very high ceilings contributed to giving the interiors a lived-in, welcoming feel. The renovations were undertaken to address winter discomfort and excessive heating costs and were partially supported by tax deductions provided by Italian legislation for building renovation.

One of the first interventions was to excavate the perimeter of the house for water drainage and to insulate the underground masonry with 12 cm thick XPS panels. The exterior was insulated with wood fiber insulation on the three sides without friezes and significant decorations. On the public side, an internal wood fiber insulation was chosen, combined with thermal plaster. The original roof structure

was preserved; it was insulated with wood fiber and a ventilated system was created using beams. A heat-recovery controlled mechanical ventilation unit allows for 24-hour air exchange. Photovoltaic panels were then installed for electricity and solar thermal panels for domestic hot water.

The project successfully preserved all the building's historic features, while simultaneously reducing energy consumption by 6.75 times (85%), from 270 kWh/m^2/year to 38 kWh/m^2/year.

The renovation followed the CasaClima certification procedure and Casa Borghesan won first prize in the 2010 CasaClima Awards in the renovation category.



Casa Borghesan – Source: archilovers.com / arch. Lucia Corti, project planner

1.3. Germany

Germany's regulatory framework for energy retrofitting of cultural heritage buildings is shaped by the interaction between federal energy policy, state-level building regulations, and heritage protection laws. While European directives are transposed at national level, both building regulation and monument protection lie within the responsibility of the individual Länder, leading to regional diversity in interpretation and implementation. At the federal level, the Building Energy Act (Gebäudeenergiegesetz, GEG), introduced in 2020 and currently being updated to integrate the provisions of the 2024 EPBD recast, provides the overarching legal basis. The GEG defines minimum efficiency standards and renewable energy requirements for new and existing buildings, while allowing flexibility for protected monuments. Article 105 explicitly states that listed or historically valuable buildings may be exempted when compliance would endanger their heritage significance or technical integrity. The act therefore establishes a system of differentiated obligations, recognising that heritage buildings require tailor-made approaches based on feasibility and cultural value. Each Land supplements this national framework through its own Monument Protection Act (Denkmalschutzgesetz), which determines the legal procedures for alterations on protected assets. These state laws generally place preservation above energy performance targets: interventions must be justified, reversible, and compatible with the visual and material integrity of the monument. Building authorities and heritage offices work closely together to evaluate proposed measures, balancing conservation priorities with energy efficiency goals. In practice, this cooperation gives rise to negotiated

outcomes, where insulation materials, window replacements, or renewable energy installations are assessed on a case-by-case basis.

Public incentive schemes further reinforce this regulatory structure. Under the KfW "Efficiency House Monument" programme and BAFA funding lines, owners can access subsidies for heritage-adapted retrofit solutions. These initiatives require prior approval from local monument authorities and detailed documentation of the proposed works. By linking technical performance evaluation with cultural oversight, they have helped to develop a shared planning culture that bridges energy policy and monument conservation. Knowledge transfer and research play an increasingly important role as well. Federal programmes such as the BMBF's initiative "Forschung in der Denkmalpflege" and the Nationale Denkmalschutzkonzeption promote the testing of retrofit techniques that reconcile preservation with climate objectives.

A clear understanding of the German system requires attention to its multi-level governance and decentralized structure. REF _Ref213925516 \h Figure 5 presents the distribution of institutional responsibilities.

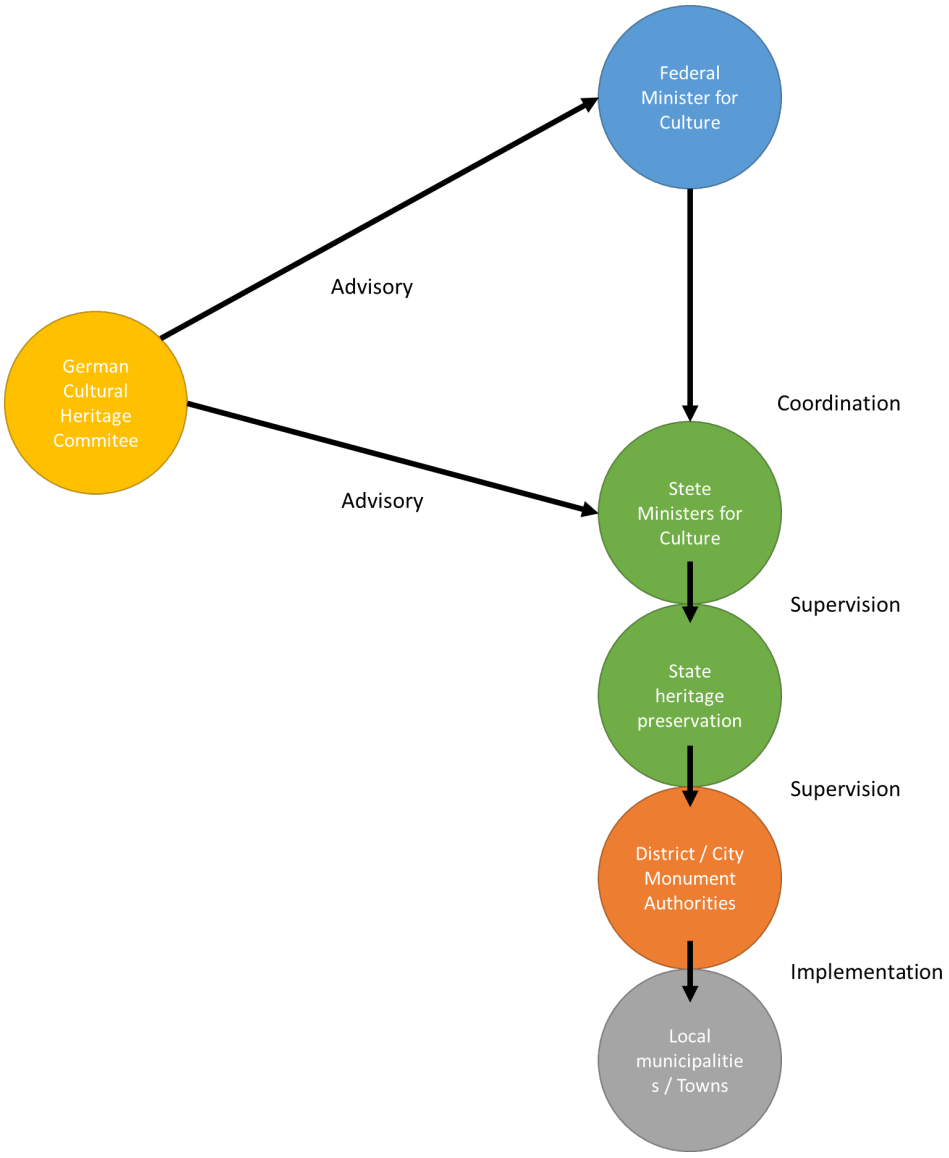


Figure 5 Institutional framework for monument protection in Germany

At the federal level, the Federal Ministry for Culture and Media (Bundesministerium für Kultur und Medien) maintains a role of strategic leadership and coordination, supported by advisory bodies such as the German Cultural Heritage Committee (DNK). The Länder take the primary responsibility for both legislation and enforcement of heritage protection via State Ministries for Culture or Science and their Heritage Preservation Offices (Landesdenkmalämter), which provide expertise, authorization, and supervision over specific interventions. Local monument authorities at the municipal or district level (Untere Denkmalschutzbehörde) are tasked with the implementation of regulations, processing permits, and overseeing works carried out on individual sites. Coordination among these levels ensures that monument protection is tailored, context-sensitive, and responsive both to national policy goals and the unique characteristics of local cultural assets.

This multi-level system, combining federal legislation, state heritage law, and financial support instruments, provides the foundation for local implementation in culturally sensitive areas. Within this broader context, towns such as Quedlinburg represent a distinctive testing ground, where the balance between conservation obligations and energy transition targets must be negotiated within a UNESCO World Heritage framework.

1.4. Poland

Poland has implemented the EU Energy Performance of Buildings Directive (EPBD) through a dedicated law – the Act on the Energy Performance of Buildings of 29 August 2014, which came into force in March 2015[13]. The Ministry of Development and Technology (formerly Ministry of Infrastructure) is the lead authority for EPBD implementation, supported by the Building Research Institute (ITB) in developing standards and technical guidelines. This legal framework mandates **Energy Performance Certificates (EPCs)** for buildings, regular inspections of large heating/air-conditioning (HVAC) systems, and nearly zero-energy building (NZEB) standards for new constructions.

Since 2021, all newly built structures must meet stringent thermal performance requirements aligned with NZEB, and major renovations are expected to upgrade energy performance where feasible[14,15]. A Central Register of Energy Performance of Buildings (CRCEB) was established to record EPCs and inspection reports, improving compliance tracking. Recent amendments have broadened the EPC obligation to a wider range of buildings (essentially all dwelling types and many non-residential buildings during sale or lease) and introduced sanctions for non-compliance[16]. From April 2023, sellers/landlords must provide a valid EPC to buyers or tenants, with fines up to 5,000 PLN for failing to do so. Furthermore, as part of the EU Green Deal goals, Poland plans to introduce a unified **energy rating scale** from A to G for buildings and stricter minimum efficiency benchmarks for renovations. A new regulation (expected by 2026) will standardize EPC formats and require that buildings undergoing major retrofit meet higher energy standards, insofar as this is technically and economically achievable. These steps align with Poland's climate commitments under its National Energy and Climate Plan 2021–2030 and the forthcoming National Building Renovation Plan (KPRB), which charts a path to decarbonize the building stock by 2050. Notably, however, Polish law has so far **carved out exceptions for historic buildings** – recognizing that strict efficiency mandates cannot override heritage preservation imperatives. The 2014 Act explicitly exempted buildings protected under monument legislation from the EPC requirement[17], and such buildings have generally not been subject to the same thermal upgrade rules as ordinary buildings.

[13] https://www.ca-epbd.eu/countries/poland

[14] Climate-neutral historic buildings, Slowacki Theatre in Poland - case study

[15] https://bww-kancelaria.pl/en/revision-of-the-epbd-facts-and-myths/

[16] https://cms-lawnow.com/en/ealerts/2023/04/poland-issues-new-obligations-on-energy-performance-certificates-in-april

[17] https://konserwator.nid.pl/media/procedure_standard/standardy-termomodernizacji-obiekto-w-zabytkowych.pdf

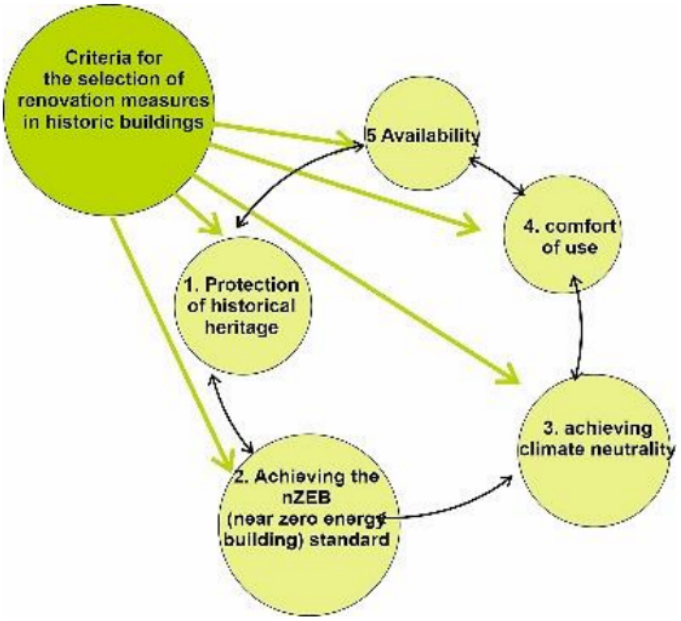


Figure 6 Criteria proposed by the authors that must be taken into account when working towards the climate neutrality of a historic building (source: https://www.researchgate.net/publication/380851554_Climate-neutral_historic_buildings_Slowacki_Theatre_in_Poland_-_case_study)

In practice, "historical value and the protection of national heritage must come first" for listed buildings, and they have been **exempt from needing to improve energy performance** if such work would compromise their character. This exemption, grounded in Article 3 of the Act, acknowledged that imposing standard insulation or window replacement in a Baroque church or centuries-old townhouse could *"mean destruction of [its] historic value"*[18]. Thus, until now, Poland's transposition of the EPBD has enforced energy standards broadly across the building sector while allowing flexibility for heritage structures. However, this balance is evolving with new EU policies – the latest EPBD recast (adopted 2024) **eliminates the blanket exemption for monuments**, instead urging that even historic buildings be assessed for potential efficiency measures (so long as they uphold heritage significance). Consequently, Poland is preparing changes to include protected buildings in its energy strategy. In September 2025 the Ministry of Development and Technology announced that upcoming regulations will **require EPCs for historic properties** upon sale or rental – ending the previous opt-out. Importantly, officials clarified that obtaining an EPC for a monument *"will not force modernization works but will serve as an impetus for planning them"*[19]. This reflects a shift in philosophy: from excluding heritage buildings entirely, to encouraging their owners to consider improvements that save energy without harming cultural value. In tandem, the government's draft **National Renovation Plan** emphasizes retrofitting even heritage buildings where possible, and calls for unified guidelines so that conservation officers across all regions apply consistent criteria when evaluating energy upgrades in monuments. In short, Poland's EPBD implementation is moving toward a more inclusive approach that integrates energy and heritage goals, supported by new standards, funding (e.g. enhanced "Clean Air" and renovation subsidy programs), and strategic planning at the national level.

[18] https://konserwator.nid.pl/media/procedure_standard/standardy-termomodernizacji-obiekto-w-zabytkowych.pdf

[19] https://www.money.pl/gospodarka/zmiany-w-certyfikatach-energetycznych-obowiazek-obejmie-zabytki-7203273003338400a.html

1.4.1. Heritage Conservation Laws and Authorities in Poland

The protection of architectural heritage in Poland is governed by the Act on the Protection and Care of Monuments of 23 July 2003 (with later amendments). This law establishes a framework in which any alteration, repair, restoration or change of use of a listed historic building must receive prior approval from heritage authorities. The system is centralized under the **General Inspector of Monuments** (Chief Conservator), who operates within the Ministry of Culture and National Heritage. The General Inspector sets national conservation policy – including a multi-year "National Program for the Protection of Monuments" adopted by the Council of Ministers – and oversees its implementation in cooperation with other bodies. Day-to-day regulatory control is exercised by the **Voivodeship (Provincial) Conservators of Monuments**, officials in each region (voivodeship) appointed by the General Inspector and the regional governor. These conservators maintain the regional heritage register and are the authorities who issue or deny permits for any works on protected sites.

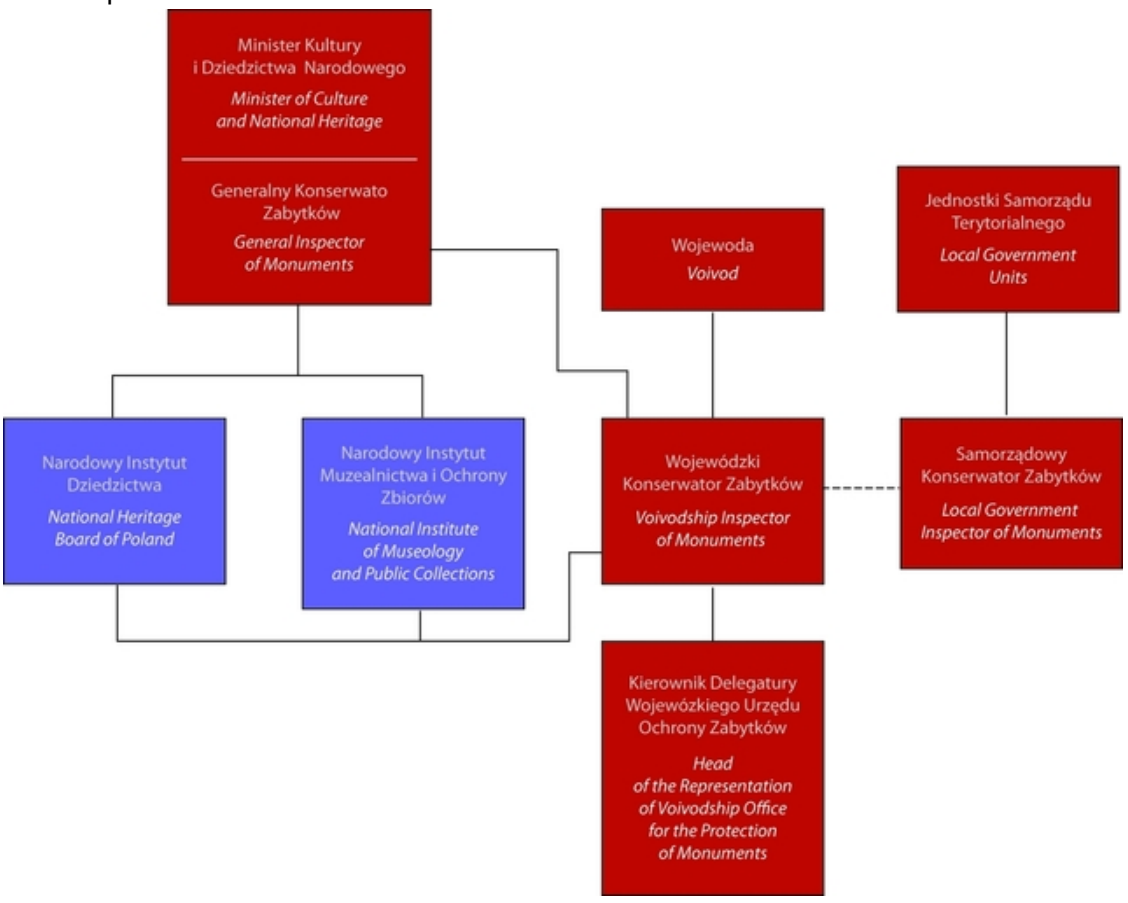


Figure 7 institutional framework in Poland (source: https://www.coe.int/en/web/herein-system/poland)

Owners of listed buildings bear legal responsibility for their upkeep: the Monument Protection Act explicitly obliges owners (or long-term holders) to ensure that the monument is maintained in the best possible condition, preserved from damage or decay. Owners must use the building in a way that "ensures the permanent preservation of its values", and they are expected to carry out necessary conservation or maintenance works (often with the help of state or local subsidies). If an owner fails to care for a monument and allows it to deteriorate, the authorities can enforce maintenance or even carry out repairs at the owner's expense under the law's provisions. In practice, this means even improving energy efficiency (e.g.

fixing windows or heating systems) is part of an owner's stewardship duties, provided it does not harm the building's heritage features[20].

Crucially, any substantive intervention in a historic building – whether installing insulation, replacing windows, upgrading the heating system, or even something as minor as changing exterior paint color – **requires a conservation permit**. The Warsaw city conservator's office underscores that "every entity, even municipal units, must obtain permits from the Provincial Conservator of Monuments" for projects in historic areas. An application for such a permit must include detailed architectural plans, technical documentation, and often conservation expert studies justifying that the proposed works will not adversely affect the monument's fabric. Only after the conservator's approval (an administrative decision) can a project proceed, and in many cases a separate building permit from the local construction authority is needed as well – effectively a dual control system. This permitting process is more time-consuming and stringent than for non-protected buildings, as it involves careful scrutiny of materials and methods to ensure compatibility with historical materials[21].

For example, when a historic townhouse undergoes renovations, the conservator may stipulate that original wooden window frames be retained and restored rather than replaced, or that any added insulation be installed on inner walls so as not to alter the external façade. The underlying philosophy, reflected in Polish heritage regulations and international charters, is that **interventions should be reversible and minimize impact** on original building fabric. Thus, conservation offices often allow modern systems to be added if done subtly: one can upgrade heating, lighting, or insulation in a monument, but the changes must be done "invisibly" or in a way that can be undone in the future. As a Council of Europe summary observes, in Poland "the state administration authorities are responsible for the protection of monuments, and the owners/holders of monuments are responsible for taking care of monuments"[22].

The public authorities (through the conservators) act as guardians of heritage, empowered to prevent inappropriate alterations, while owners are partners in preserving the building and are expected to invest in its maintenance. This dynamic creates a framework where energy efficiency measures are not forbidden – but they are subject to case-by-case negotiation to ensure **heritage values are not compromised**.

1.4.2. Balancing Energy Efficiency with Heritage Preservation

Reconciling the goals of energy conservation and monument conservation is a delicate task. Poland's approach to this balance has been one of cautious integration: broadly encouraging improvements in building efficiency, while explicitly recognizing that historic structures require special treatment. **In legal terms**, Poland's building regulations have long permitted exemptions or relaxed standards for heritage buildings. For instance, Poland's technical construction norms (which set minimum thermal insulation levels for walls, roofs, windows, etc.) include provisions that allow historic buildings to deviate from modern insulation requirements if meeting those standards would threaten their architectural integrity. Likewise, as noted earlier, the EPC law excluded monuments from the certification mandate on the premise that many such buildings could not attain high energy ratings without extensive (and unacceptable) alterations[23].

These carve-outs stem from EU rules themselves: the earlier version of the EPBD allowed countries to exempt protected buildings on the grounds of preserving cultural heritage. As a result, until recently, **listed buildings were simply not subject to thermal retrofit obligations** – their inefficient energy performance was tolerated as the price of conservation. However, the policy landscape is shifting. The 2018 update of the EPBD (Directive 2018/844) was a game-changer: it introduced, for the *first* time, an encouragement to

[20] https://www.coe.int/en/web/herein-system/poland

[21] https://energy-cities.eu/challenges-in-modernising-public-lighting-in-historical-areas-of-the-city

[22] https://www.coe.int/en/web/herein-system/poland

[23] https://konserwator.nid.pl/media/procedure_standard/standardy-termomodernizacji-obiekto-w-zabytkowych.pdf

improve the energy performance of historic and culturally significant buildings "while ensuring the protection and preservation of cultural heritage". This marked a departure from viewing heritage buildings solely as exceptions, and instead framed them as part of the climate solution – albeit with *bespoke* solutions. Building on that, the new EPBD 2024 goes further by removing a blanket exemption and promoting **research and innovation in retrofitting historic buildings**. In Poland, these principles are being cautiously put into practice through guidelines and pilot projects[24].

The **General Inspectorate of Monuments and the National Heritage Board of Poland (NID)** have been proactive in examining how to increase energy efficiency in heritage buildings without sacrificing authenticity. In 2020, the General Inspector (then Prof. Magdalena Gawin) issued guidance to all regional conservators on "thermomodernization of historic buildings". This guidance acknowledged that improving energy performance in monuments is increasingly necessary – *"thermal modernization of buildings has now become a necessity"* given climate targets and the rising expectations for comfort and low utility costs. At the same time, the letter emphasized a critical point: *"Polish law allows exceptions for historic buildings – even complete ones – especially if thermal upgrading would mean destroying heritage values"*. In other words, efficiency is important, but **heritage comes first**. The guidance noted that across Europe, building code insulation requirements are typically relaxed for historic structures, and urged conservators to approach energy retrofit proposals with both openness and caution. A key excerpt states: *"One must remember that historic buildings are a specific group of objects. Their thermal upgrading cannot proceed in a haphazard way, determined solely by economic factors"*[25]. Instead, any energy-saving measures must be carefully designed to respect the building's historic fabric and allow reversal if needed.

In practical terms, Polish conservation services now often **work together with engineers and architects** to find acceptable solutions on a case-by-case basis. For example, if an owner of a 19th-century tenement house wants to insulate the building to reduce heating costs, outright application of standard external insulation (e.g. EPS foam on the façade) would be prohibited, as it would irreversibly alter the appearance and trap moisture in historic walls. The compromise frequently recommended is to use internal insulation systems that are vapor-permeable and reversible. Materials like calcium-silicate or wood-fibre insulating boards can be applied to the inside of masonry walls to improve thermal resistance, while the exterior brick or stucco is left unchanged. Even then, conservators demand rigorous analysis of moisture dynamics – ensuring that adding insulation won't cause condensation and mold within the old walls.

Any such plan typically must be supported by hygrothermal modeling and often a pilot section to monitor effects. Another area is **windows**: historic wooden windows are character-defining elements, and rather than swapping them for new double-glazed units, the approach is to refurbish the originals (restoring frames, adding weather stripping) or install a second layer of glazing on the interior side – thus improving efficiency while *"retaining the original woodwork."* In many Polish cities, including Warsaw, Kraków, and Zamość, projects have successfully tightened the building envelope of heritage homes by using secondary glazing and insulating shutters, without removing antique windows. Similarly, heating systems can often be upgraded in a non-intrusive way: old coal- or oil-fired boilers in basements of historic buildings have been replaced with modern gas boilers or air-source heat pumps located discretely in courtyards, and in some cases buildings are connected to district heating networks to eliminate on-site emissions. These changes require conservator sign-off for any visible components (for instance, routing new pipes or installing an outdoor heat pump unit on a historic wall), but generally are approved if they do not mar the building's appearance. Even the lighting in historic districts is being modernized carefully – *e.g.* Warsaw's municipal retrofit project under the SmartEPC initiative is replacing thousands of old street lanterns in the Old Town and other historic areas with LED luminaires designed to mimic the antique style. This improves energy efficiency and illumination quality, but as the project manager notes, it required lengthy archival research to design

[24] https://www.researchgate.net/publication/380851554_Climate-neutral_historic_buildings_Slowacki_Theatre_in_Poland_-_case_study

[25] https://konserwator.nid.pl/media/procedure_standard/standardy-termomodernizacji-obiekto-w-zabytkowych.pdf

fixtures indistinguishable from the historic originals, and every prototype had to be cleared by heritage officials[26].

Overall, the Polish experience illustrates a **negotiated balance** between efficiency and preservation. Energy improvements are not only allowed but increasingly encouraged in monuments – yet always under the condition that the building's cultural value is safeguarded. This reflects the spirit of standard EN 16883:2017 ("Conservation of cultural heritage – Guidelines for improving energy performance of historic buildings"), which has been embraced in Poland's conservation and building communities. EN 16883 provides a methodology for retrofitting historic buildings by first understanding their heritage significance, then evaluating compatible measures. A recent case study applying EN 16883 in Poland is the ongoing retrofit of the **Juliusz Słowacki Theatre in Kraków**, a landmark 19th-century theater. Planners there conducted a full heritage assessment – documenting the ornate interiors, frescoes, and façade – **before** selecting any energy measures. Through multidisciplinary research, they mapped which elements were most sensitive and which could be altered. The theatre, which aims to become a "climate-neutral" historic building, has seen upgrades implemented in phases. Contractors improved insulation in the attic and roof (areas invisible to visitors) and insulated certain wall sections from the inside where thick masonry allowed it, carefully avoiding any damage to historic finishes. The heating and ventilation systems were modernized as well: old gas boilers were replaced with a biomass boiler and high-efficiency heat pumps, complemented by solar panels hidden on a flat roof section. According to the engineers' analysis, achieving near-zero energy use in this listed building was possible only by combining comprehensive thermal improvements *approved by the conservator* with a switch to renewable energy sources (heat pumps powered by PV). Crucially, all changes had to be reversible or concealed – for instance, insulation boards were installed behind existing ornamental wood paneling, and new HVAC ducts run through existing chases to avoid new visual intrusions. The Słowacki Theatre project, documented in a 2024 conference paper, demonstrates that even a protected monument can drastically cut energy demand (by an estimated 60% or more) while preserving its aesthetic and historic integrity. It serves as a model for other historic public buildings in Poland[27].



Figure 8 Juliusz Słowacki Theatre in Kraków by night. (fot. Jan Mehlich)

[26] https://energy-cities.eu/challenges-in-modernising-public-lighting-in-historical-areas-of-the-city/

[27] https://www.researchgate.net/publication/380851554_Climate-neutral_historic_buildings_Slowacki_Theatre_in_Poland_-_case_study

1.4.3. Heritage energy retrofits in Zamość

The historic Dom Centralny ("Centralka", built 1910-11) on Zamość's Old Town square, undergoing façade and roof restoration in April 2024. The city launched a full conservation-and-modernization project for this Secessionist tenement in April 2024, to be completed by June 2025. The PLN ≈3.3 M program – 98% co-funded by Poland's national monuments fund – covers renovation of all façades and balconies, a practically new roof (with chimneys) and four staircases, plus upgrading of internal utilities (water/sewer and heating). All works follow strict conservation guidelines (no new decorative elements) while adding modern insulation and upgraded HVAC/piping to improve the building's thermal performance[28,29].



Figure 9 The historic Dom Centralny (source:https://zamosc.eska.pl/rozpoczyna-sie-remont-centralki-to-jedna-z-najpiekniejszych-kamienic-w-zamosciu-aa-ox58-pYPw-z4jA.html)

In parallel, Zamość has applied similar energy upgrades to other historic public buildings. For example, Primary School No. 6 on ul. Orla was thermally modernized (ca. 2019–20) under an EU-funded program (≈PLN 1.3 M). The scope included replacing old windows, insulating all exterior walls (new façade finish) and even insulating the gymnasium floor, along with a new heating system. These measures greatly reduced

[28] https://tuzamosc.pl/20240411602775/remont-zabytkowej-centralki-na-starym-miescie-juz-sie-rozpoczal-art-116

[29] https://zamosc.eska.pl/rozpoczyna-sie-remont-centralki-to-jedna-z-najpiekniejszych-kamienic-w-zamosciu-aa-ox58-pYPw-z4jA.html

heat loss while preserving the school's historic character. Projects like these – combined with municipal heritage grant schemes and the city's 2023–30 revitalization plan – illustrate Zamość's approach of pairing conservation with energy-efficiency upgrades in its protected old town district.

Zamość is a UNESCO-listed Renaissance city ("Pomnik historii")[30], and its Old Town (Stare Miasto) is protected as a national monument. In recent decades the city and region have pursued energy-related upgrades of historic structures under various programs. Below are several illustrative projects (2020s and earlier) involving protected or architecturally significant buildings in Zamość. Each combined thermal/energy retrofit with preservation, and was supported by EU or national funds.

- **Ośrodek Edukacji Ekologicznej i Strzelectwa (ul. Źródlana 1A)** – The former orphanage building (relic of Zamość's early 20th-century social history) is being transformed into an ecological education and hunting heritage center (run by the city, Polish Hunting Assoc., and Roztocze National Park). A deep "green" retrofit (completed 2024) vastly improves its energy profile. Works include high-performance wall insulation, new high-efficiency windows, and an energy management system. Renewable systems are integral: plans include rooftop photovoltaics and ground-source heat pumps. The goal is near-passive performance. The ~PLN 10 million investment was co-financed by the National Fund for Environmental Protection (NFOŚiGW) and the Polish Hunting Association[31].
- **Ratusz Miejski (Town Hall, ul. Rynek Wielki 13)** – The late-Renaissance town hall, a UNESCO core landmark, underwent heritage restoration in 2025 with some energy components. The focus was restoring its historic stone staircase and finishing touches, but the project also included *partial* modernization of the central heating system. This renovation was funded almost entirely by Poland's "Historic Monuments Recovery" programme (95% grant), with the city contributing the balance. Though relatively small in scale (~PLN 0.42M), it explicitly noted upgrading the CO installation within the protected building.[32]



Figure 10 The late-Renaissance town hall (source:https://zyciezamoscia.pl/informacje/renowacja-schodow-ratusza-miejskiego-w-zamosciu/)

- **Hotel Zamojski & SPA (ul. Kołłątaja 2-6)** – This historic multi-building hotel complex (in Old Town) was included in an EU-REACT project for private enterprises. A 2022 tender (RPO Lubelskie 2014-

[30] https://www.pot.gov.pl/pl/fundusze-ue/pomysly-na-projekt-turystyczny/rewitalizacja-zabytkowego-starego-miasta-w-zamosciu-i-etap

[31] https://radio.lublin.pl/2023/10/miliony-na-oszczednosc-powstaje-osrodek-edukacji-ekologicznej-i-strzelectwa-zdjecia/

[32] https://zyciezamoscia.pl/informacje/renowacja-schodow-ratusza-miejskiego-w-zamosciu/

20, Axis 15 REACT-EU) covers thermomodernization of "Hotel Zamojski"[33]. Scope (still underway) includes modernizing the central heating and domestic hot water systems – for example, replacing convectors and installing two 30 kW air-to-water heat pumps. This public-sector call for bids confirms EU co-funding (project RPLU.15.01.00-06-0537/22).

Each of these examples involves a historic or heritage-protected building in Zamość (schools, municipal offices, hotels, etc.) and combines energy upgrades with conservation. They were funded by programs like EU Cohesion (RPO), national culture/heritage funds, and municipal budgets. (For instance, the Town Hall stairs project used the Polish Historic Monuments Fund, while the two hotels used RPO/EU funding.) Collectively, they demonstrate a range of retrofit methods – wall/roof insulation, new windows and HVAC, controls and renewables – applied in a way that respects Zamość's architectural heritage

A further example comes from **Warsaw's Old Town**, a World Heritage site reconstructed after WWII. Over the past decade, the City of Warsaw has undertaken projects to improve energy efficiency in the Old Town's historic tenement houses, many of which are municipal-owned. One initiative upgraded the heating of several 17th–18th century apartment buildings by connecting them to the city's district heating grid, allowing old coal furnaces to be removed. The switchover significantly reduced indoor air pollution and heat loss (since modern heat exchangers provide steady heat), but it was executed without altering the buildings' historical interiors – the new pipes were routed through existing chimneys and service ducts so as not to disturb decorative finishes. At the same time, the city invested in **retrofitting historic windows**: rather than replacing the prized original wooden sash windows, craftsmen restored them and added internal secondary glazing panels that are virtually invisible from outside. This improved thermal performance and comfort for residents while *retaining the original woodwork and glass* that contribute to the Old Town's authenticity. Even lighting in the stairwells and courtyards was upgraded to LED, using fixtures designed to look like antique lanterns. These efforts in Warsaw exemplify how local governments in Poland are trying to lead by example – proving that protected historic housing can be made more energy-efficient through sensitive renovations, all under the close supervision of conservators. As one Warsaw conservator noted, *"We will not compromise the appearance of a World Heritage site for efficiency, but we will find ways to improve comfort discreetly"*. The result is a set of best practices (insulating attics, sealing windows, efficient heating systems, LED lighting) that are now being shared with other historic city centers.

[33] https://bazakonkurencyjnosci.funduszeeuropejskie.gov.pl/api/files/1289668



Figure 11 Warsaw city old town square (source: https://www.inyourpocket.com/warsaw/old-town-square_148432v)

1.4.4. Conclusions

Poland's experience demonstrates that **broad enforcement of building energy standards can coexist with heritage protection**, provided there is flexibility and dialogue between the energy and conservation domains. Initially, Poland implemented the EPBD with carve-outs for monuments – effectively postponing efficiency concerns for that subset. Over time, driven by EU climate goals and mounting pressure to revitalize old buildings, the policy has shifted towards engaging the historic building stock in energy-saving efforts. The key has been to do so *on heritage-friendly terms*. Institutions have adjusted: the Ministry of Culture and National Heritage, through the General Inspectorate of Monuments and advisory bodies like NID, has issued guidelines to integrate energy efficiency into conservation practice. The Ministry of Development and Technology, for its part, has worked on regulations (like the upcoming EPC methodology in 2026) that incorporate special provisions for historic buildings – such as alternative compliance paths or recommended bespoke solutions. Both ministries appear to recognize the need for collaboration. Indeed, experts have called for joint training and "one-stop" guidance so that energy auditors, retrofit designers, and heritage conservators can develop a common language. Pilot projects (Kraków, Zamość, etc.) have provided local data and examples to inform such guidance. A proposal under discussion is to create a standardized protocol for energy audits of historic buildings, which would identify which improvements are acceptable case-by-case and require sign-off by a licensed conservator–architect duo. Financial resources are also being aligned with this integrated approach. Poland's government has expanded grants for improving the energy efficiency of homes (e.g. the "Clean Air" program and EU structural funds) and is considering earmarking a portion specifically for historic buildings, since these often have higher retrofit costs. EU recovery funds and Norway Grants have already supported some pilot renovations of monuments with energy upgrades (for example, insulated roofs and modern HVAC in historic museums and schools).

As of late 2025, a clear trend is that **historic preservation is no longer seen as a roadblock to climate action**, but rather as a field where innovative solutions can shine. Poland's forthcoming National Renovation Plan (KPRB) explicitly integrates heritage, ensuring that the drive to decarbonize buildings by 2050 will include castles and cathedrals alongside cottages and condos. The removal of the EPC exemption for monuments symbolizes this new mindset: even if these buildings won't be hitting top energy classes soon, they will at least be accounted for and analyzed, creating knowledge and impetus for future improvements.

Conservation authorities, too, are adapting – some have suggested that every regional conservator's office should employ an energy-efficiency specialist to evaluate proposals and advise owners on best practices. In summary, Poland's "negotiated balance" approach – enforce EPBD measures broadly, grant case-by-case flexibility for monuments, and gradually tighten the integration between the two – could serve as a model for other countries. It shows that with careful planning, historic buildings can reduce energy waste and even approach modern performance levels, all while *keeping their soul*. The coming years will likely see more examples like the Kraków theatre or the Zamość old town, as policy support and technical know-how continue to grow. Poland's dual commitment to its cultural heritage and to energy transition suggests that the two goals, far from being mutually exclusive, can be mutually reinforcing – creating a **sustainable future for the past**.

C. PROCEDURE FOR IMPLEMENTING ENERGY RENOVATION OF BUILDINGS WITH THE STATUS OF CULTURAL PROPERTY

1. Neighbourhood definition and boundary setting

Before any building-level documentation is prepared, the cultural heritage neighbourhood must be formally defined as a spatial, technical and governance unit. This step establishes the territorial and analytical framework within which all subsequent energy and conservation decisions will be made. Without such a definition, individual building retrofits risk becoming fragmented, sub-optimal, or even contradictory to each other, especially in dense historic fabrics where buildings, infrastructure and public space are physically and functionally interdependent.

A cultural heritage neighbourhood is not merely a collection of protected buildings. It is an integrated urban system composed of historic structures, streets, courtyards, utilities, ownership structures, and social uses, all embedded within a legally defined conservation regime. In historic city centres, energy flows, moisture behaviour, ventilation patterns, shading, and access to renewable energy are strongly influenced by urban morphology: party walls, street widths, courtyard layouts, roof continuity, and orientation. Consequently, energy performance and heritage protection cannot be optimised at the level of a single building without understanding its position within the wider ensemble.

The first task in Step 0 is the **delineation of neighbourhood boundaries**. These boundaries should normally follow existing heritage protection zones (e.g. UNESCO core areas, conservation zones A–C, historic urban ensembles), but they may also be adjusted to reflect energy-system logic, such as the extent of a district heating network, a shared courtyard system, or a coherent block of buildings with similar construction typologies. The aim is to define a spatial unit that is meaningful both from a conservation perspective and from an energy-system perspective.

Once boundaries are established, a **neighbourhood inventory** must be prepared. This inventory aggregates information that is usually scattered across individual building files and municipal databases, creating a unified baseline. It includes:

- **Building typologies**: classification of buildings by age, construction system (e.g. masonry, timber floors, vaults), height, roof form, façade protection level, and functional use (residential, mixed-

use, public, commercial). This allows grouping of buildings with similar thermal behaviour, retrofit constraints and conservation sensitivity.

- **Heritage and planning constraints**: mapping of protection categories, listed buildings, protected façades, roofscape controls, archaeological zones, and public-space protection. These constraints determine what types of interventions are legally and culturally permissible at both building and district scale.
- **Energy infrastructure**: identification of existing heating networks, substations, gas and electricity grids, transformer capacity, potential district heating loops, waste heat sources, and renewable energy opportunities (e.g. roof areas suitable for photovoltaics, ground potential for heat pumps, biomass or geothermal options).
- **Public space and microclimate**: streets, squares, courtyards, green areas, shading patterns, wind corridors and urban heat-island effects. These factors strongly influence heating and cooling demand and the feasibility of passive measures such as shading, night ventilation, or evaporative cooling.
- **Ownership and governance structure**: mapping of public vs private ownership, housing associations, condominium arrangements, heritage authorities and utility providers. This is critical for understanding decision-making processes, cost sharing, and the feasibility of collective energy solutions.

Based on this information, a neighbourhood energy baseline is established. Rather than summing up EPCs of individual buildings, this baseline looks at the neighbourhood as a whole: total heat demand, peak loads, electricity consumption, seasonal profiles, and emissions. It also identifies structural inefficiencies that are invisible at building scale, such as oversized boilers, underused network capacity, or the inability of individual buildings to integrate renewables due to heritage constraints that could be solved through shared systems.

Equally important is the heritage baseline at neighbourhood scale. This goes beyond listing individual monuments and assesses the ensemble character: visual coherence, roofscape continuity, street rhythm, material palettes, and historically significant spatial relationships. Many energy interventions—solar panels, external units, ventilation outlets, shading devices—have cumulative visual and material impacts that only become apparent when viewed across the whole district. The neighbourhood baseline makes it possible to identify where interventions can be concentrated, where they must be avoided, and where collective solutions are preferable to multiple small installations.

The output of Step 0 is therefore not a design, but a strategic reference framework. It defines what types of buildings exist, what energy and heritage constraints apply, and where synergies or conflicts are likely to arise. This framework guides all subsequent building-level actions: energy audits, design of insulation, HVAC upgrades, or renewable integration are carried out with explicit reference to neighbourhood-level objectives, such as balancing energy loads, preserving coherent roofscapes, or enabling future district-wide systems.

In this way, Step 0 ensures that individual retrofits become components of a coordinated neighbourhood transformation rather than isolated technical upgrades. It operationalises the core principle of ZEB4ZEN: that zero-energy heritage districts can only be achieved when buildings are planned, renovated and managed as parts of a larger urban and energy system, not as standalone objects.

Once this neighbourhood-level reference framework has been established, individual buildings can be addressed within a clearly defined spatial, technical and heritage context, ensuring that their renovation contributes coherently to the objectives of the wider historic ensemble.

Energy retrofit of a protected (cultural property) building must follow both technical standards and heritage regulations. In the EU context, the Energy Performance of Buildings Directive (EPBD, as amended and most recently recast) explicitly recognizes historic buildings, allowing Member States to adjust or exempt heritage

buildings from standard energy requirements when compliance would "unacceptably alter their character or appearance"[34].

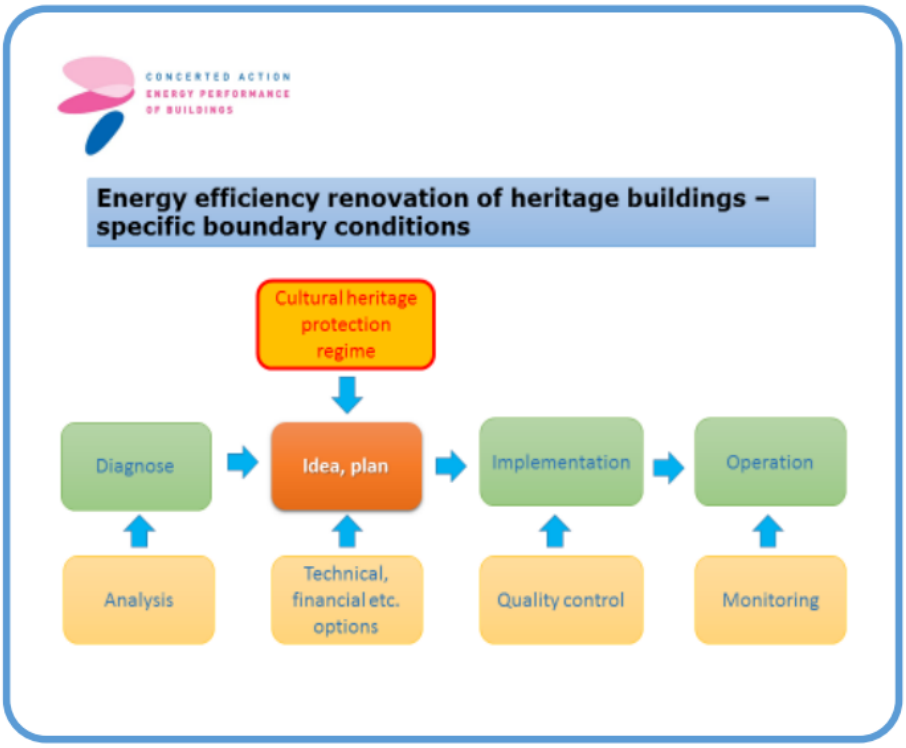


Figure 12 Renovation projects for heritage buildings are subject to additional conditions.[35]

At the same time, EN 16883:2017 (a European CEN standard) provides a systematic planning procedure for such retrofits, balancing energy goals with conservation of heritage value[3637]. An INTERREG-supported project must integrate these frameworks: project planning and documentation must meet EU rules (EPBD, funding conditions) and national heritage laws. This requires assembling a multidisciplinary team (architects, engineers, conservators, etc.) from the outset. For example, EN 16883:2017 explicitly **"requires that a multidisciplinary team is involved"** in the planning process, ensuring engineers and conservators jointly negotiate compatible solutions. Through such interdisciplinary dialogue, stakeholders can **"arrive at a solution that balances energy conservation and building conservation"** for each building[3839].

In practice, the project documentation package includes parallel streams for energy and heritage: survey reports, design drawings, and permit applications. Key documents include the heritage value statement, a detailed building survey (geometry and condition), an energy audit or modelling study, and design drawings of the proposed measures (insulation, HVAC systems, window upgrades, etc.), each annotated to show compliance with conservation criteria. The team coordinates these elements so that, for instance, structural engineering plans and material specifications explicitly reflect heritage constraints, and a **heritage impact assessment** is prepared for approval by the monument authority. Continuous documentation is critical:

[34] https://cdn1.gopublic.dk/epbd/Media/638373627043371380/02-CT2_Factsheet-Heritage.pdf
[35] https://cdn1.gopublic.dk/epbd/Media/638373627043371380/02-CT2_Factsheet-Heritage.pdf
[36] https://www.mdpi.com/2071-1050/13/5/2927
[37] https://www.mdpi.com/2071-1050/13/5/2927
[38] https://vbn.aau.dk/files/465798810/D.B3_Handbook.pdf
[39] https://vbn.aau.dk/files/465798810/D.B3_Handbook.pdf

detailed drawings with photos of existing fabric and interventions must record *what* changes are made and *why*, serving both regulatory review and future reference[40].

2. Project documentation

Project documentation typically unfolds in stages (concept, preliminary design, detailed design) and must include all technical and administrative elements required by EU and national frameworks. In the **initial phase**, a comprehensive survey report is produced. This includes a geometric "as-built" model (often 3D or BIM-based), a heritage significance assessment, and a condition/conservation analysis[41][42]. An energy baseline is established via energy audit or performance certificate, often supported by simulations. These feed into a feasibility study that identifies appropriate retrofit strategies compatible with the building's value (for example, "DuMo" sustainability models or local conservation guidelines, as noted in INTERREG good practices). The project brief then outlines objectives (target energy savings, comfort goals) and constraints (e.g. listed status).

Key parts of the documentation package include:

- **Building Survey and Heritage Statement:** Detailed drawings of existing walls, floors, windows, etc., and a narrative of the building's historical and architectural value. This often entails material investigations and non-destructive testing of the envelope to record original fabric. As Thravalou *et al.* report, documentation of a pilot retrofit "entails the geometrical survey, the assessment of the building's heritage significance, the conservation state analysis…" as well as climate and monitoring data[43][44].
- **Energy Audit/Analysis:** Measured energy use and thermal performance calculations, along with Indoor Environmental Quality measurements if available. The results inform which interventions (insulation, HVAC, renewable integration) are technically feasible. All assumptions and software models are documented for transparency.
- **Design and Technical Specifications:** Drawings and specifications for proposed interventions (insulation layers, window upgrades, new heating systems, etc.). Each measure is detailed with materials and methods that respect heritage constraints (e.g. vapor-permeable insulation on historic walls, frame retention for original windows). EN 16883 emphasizes that documentation should include "the interventions including drawings and photos" and "methods and materials used"[45][46], ensuring that conservators and engineers understand exactly how works will be carried out.
- **Legal/Administrative Documents:** The planning application dossier typically includes a planning permit or building permit application, and a separate heritage/conservation permit (often called a **conservation permit** or **works permit** in EU countries). The heritage permit application will contain a heritage impact statement showing how the retrofit "preserves character" (as EPBD Article 4 permits) and complies with national conservation laws. Tender documents and contracts (required for INTERREG funding) also reference standards like EN 16883:2017 to demonstrate compliance.

At each stage, the team actively involves all disciplines. EN 16883 recommends holding joint site inspections and design reviews. For instance, an architect may coordinate with a conservator to choose compatible

[40] https://www.europeanheritagehub.eu/wp-content/uploads/2024/05/2023_Thravalou-et-al_Energy-Retrofit-Strategies.pdf
[41] https://www.europeanheritagehub.eu/wp-content/uploads/2024/05/2023_Thravalou-et-al_Energy-Retrofit-Strategies.pdf
[42] https://www.europeanheritagehub.eu/wp-content/uploads/2024/05/2023_Thravalou-et-al_Energy-Retrofit-Strategies.pdf
[43] https://www.europeanheritagehub.eu/wp-content/uploads/2024/05/2023_Thravalou-et-al_Energy-Retrofit-Strategies.pdf
[44] https://www.europeanheritagehub.eu/wp-content/uploads/2024/05/2023_Thravalou-et-al_Energy-Retrofit-Strategies.pdf
[45] https://vbn.aau.dk/files/465798810/D.B3_Handbook.pdf
[46] https://vbn.aau.dk/files/465798810/D.B3_Handbook.pdf

window upgrades, while engineers ensure new HVAC ductwork avoids sensitive features. Regular stakeholder workshops (including the heritage authority where needed) help negotiate trade-offs. The project documentation thus serves both as a technical guide for construction and as an administrative submission for approvals. Because INTERREG projects are subject to EU audit, meticulous record-keeping is emphasized: all reports, drawings and change orders are archived (for example, by uploading to databases like the European HiBERatlas)[47][48].

3. Specifics of project documentation preparation

Preparing the documentation for an energy retrofit of a cultural property requires particular attention to both content and format. First, every document must be clear about heritage compatibility. For example, EN 16883 provides evaluation criteria for retrofit solutions and expects the project file to justify each choice in terms of heritage impact[49]. In practice, the reports and drawings include sections explicitly labeled "heritage compatibility" or "impact on cultural values," comparing alternative measures. This might involve quoting national conservation guidelines or case studies of similar monuments. The rationale ("why" the chosen solution was selected over others) must be documented alongside cost and energy analyses[50].

Second, the documentation is often more extensive than for a regular building. As the IEA-SHC Task 59 handbook notes, historic projects typically require *"more detailed documentation…including drawings and photos"*, and even logging of discoveries uncovered during work[51]. In an INTERREG-funded context, one must often submit a large final report including all design deliverables. Project teams may use Building Information Modelling (BIM) to manage complexity: for instance, a Heritage-BIM model can integrate point clouds, condition surveys and energy data[52][53]. Such digital documentation helps coordinate geometry (e.g. vaulted ceilings, thicknesses) with thermophysical properties, and it creates a living record for future maintenance.

Third, ensure compliance with relevant technical standards. Besides EN 16883, other standards may apply: ISO 9869 and ISO 10077 for measuring U-values or windows, EN 16247 for energy audits, national building codes (Eurocodes) for structural assessments, etc. When renewable energy or mechanical systems are installed, one checks local regulations – for example, some historic centers forbid roof PV unless inconspicuous. Any regulatory permission (building permit, environmental permit) is accompanied by supporting documents in the format prescribed by law. Throughout, interdisciplinary review is key: engineers, architects, and conservator-restorers jointly vet the final documentation for completeness.

In summary, the project documentation for retrofitting a cultural property is a comprehensive dossier that combines heritage studies, technical plans, and administrative forms. It must be compatible with EU directives (EPBD, etc.) and standards like EN 16883[54][55], and explicitly show how each measure respects the building's cultural values. By maintaining continuous, detailed records (with explanations of what was done, how and why) and by coordinating across disciplines[56], the documentation ensures both regulatory approval

[47] https://vbn.aau.dk/files/465798810/D.B3_Handbook.pdf
[48] https://vbn.aau.dk/files/465798810/D.B3_Handbook.pdf
[49] https://www.mdpi.com/2071-1050/13/5/2927
[50] https://vbn.aau.dk/files/465798810/D.B3_Handbook.pdf
[51] https://vbn.aau.dk/files/465798810/D.B3_Handbook.pdf
[52] https://www.europeanheritagehub.eu/wp-content/uploads/2024/05/2023_Thravalou-et-al_Energy-Retrofit-Strategies.pdf
[53] https://www.europeanheritagehub.eu/wp-content/uploads/2024/05/2023_Thravalou-et-al_Energy-Retrofit-Strategies.pdf
[54] https://www.mdpi.com/2071-1050/13/5/2927
[55] https://www.mdpi.com/2071-1050/13/5/2927
[56] https://vbn.aau.dk/files/465798810/D.B3_Handbook.pdf

and a sustainable outcome: improved energy performance **without compromising the building's historic integrity**[57].

D. ENERGY EFFICIENCY MEASURES ON BUILDINGS WITH THE STATUS OF CULTURAL PROPERTY

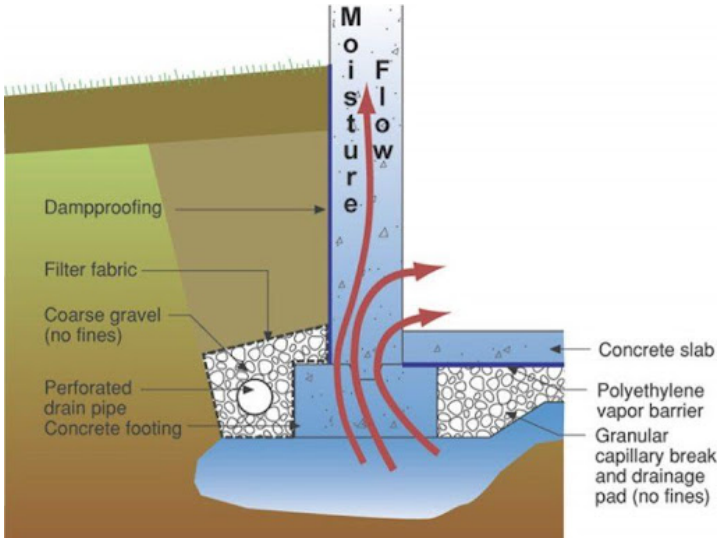
1. Moisture rehabilitation as a prerequisite for energy/comprehensive renovation

Historic buildings under formal protection often bear constructions from heterogeneous materials (brick, natural stone, lime-based mortars, timber), which present particular vapor and moisture transport behaviors. Before any energy retrofit or insulation work is attempted, rehabilitation of moisture-related pathologies must be addressed, or else added thermal barriers may exacerbate damage rather than prevent it.

1.1. Sources and Mechanisms of Moisture in Historic Buildings

Several sources of moisture threaten heritage masonry and must be carefully understood before any intervention is considered. Unlike modern constructions, historic buildings were often erected without systematic waterproofing or damp-proof courses, making them inherently vulnerable to moisture-related damage.

- Rising damp (capillary moisture): In the absence of effective horizontal damp-proof courses (DPC) or where existing barriers have deteriorated, groundwater is drawn upward by capillary forces in porous masonry elements such as brick, stone, or lime mortar. The extent of rising damp depends on pore size distribution, wall thickness, evaporation conditions, and the presence of soluble salts. In heritage masonry, the problem is aggravated by the use of lime mortars, which are highly porous and allow water to migrate freely. Rising damp typically manifests as damp patches up to one meter above ground level, but in some cases it can extend significantly higher, leading to persistent wall saturation and salt efflorescence.



[57] https://www.mdpi.com/2071-1050/13/5/2927

Figure 13 Rising damp (source: https://deltaacademy.dorken.com/wp-content/uploads/2020/10/dorken-6.jpg)

- Rain-driven water infiltration: Wind-driven rain or surface splash can enter through open joints, fissures, or degraded external renders. Exposed façades in historical city centers—often tall, narrow and directly facing streets—are particularly prone to this form of wetting. Prolonged exposure may result in disintegration of surface finishes, plaster detachment, and erosion of stone or brick. In colder climates of Central Europe, repeated freeze–thaw cycles exacerbate the deterioration of wetted surfaces. Moreover, traditional heritage façades, with decorative elements and recesses, present more complex geometries that enhance water retention and channel rainwater into sensitive areas.



Figure 14 Moisture damage on a historic brick façade caused by rain: damp, stained and deteriorated masonry below the roof edge and coping, typical of driving rain and uncontrolled water run-off (source:https://www.ids-dmv.com/masonry/how-rain-affects-a-brick-building-facade-part-i/)

- Interstitial condensation: When warm, humid indoor air penetrates masonry and meets colder external layers, interstitial condensation may occur within wall assemblies or cavities. This is particularly problematic in retrofitted buildings where internal insulation reduces wall surface temperature, shifting the dew point into the structure. In historic buildings, where vapor diffusion must not be obstructed, condensation leads to mold growth, wood decay in embedded beams, and long-term weakening of mortars. The problem is compounded by limited possibilities for installing modern vapor barriers, due to heritage restrictions.



Figure 15 Interstitial condensation - wooden elements

(source:https://www.ecohome.net/media/articles/images/5e/7c/5e7c8ec7c764c166f2217f0647674f8c3eb72b01/thumbs/g07lEH9nnyvM_1200x675_WjXQ-FAc.jpg)

- Accidental or bulk water ingress: Leaks from defective plumbing systems, roof failures, or blocked gutters can saturate building fabric in a short time. Flooding events or rising groundwater tables also contribute to sudden and severe wetting. Heritage buildings, which often have limited or outdated drainage infrastructure, are especially at risk. Once water penetrates thick masonry, drying is extremely slow, leading to sustained high moisture content that compromises both structural performance and the feasibility of energy retrofit measures.



Figure 16 Depiction of severe, localized wall saturation and plaster damage, resulting from a sudden event like a plumbing leak or a failure of the roof/gutter system (source: https://ppgutters.co.uk/the-most-common-gutter-problems-in-older-uk-homes)

- Hygroscopic salts: Dissolved salts such as chlorides, nitrates, and sulfates are frequently present in historic masonry, originating from soil contamination, historical construction materials, or previous inappropriate interventions. These salts attract and retain atmospheric moisture even at relatively low humidity levels. As a result, walls remain damp despite surface drying, and cyclic crystallization of salts within pores causes spalling, powdering, and continuous degradation of plasters. Salt-contaminated masonry represents one of the most challenging conditions for conservation and energy renovation, since salts perpetuate a self-reinforcing moisture cycle.



Figure 17 Salts (source:https://oaks-preservation.co.uk/wp-content/uploads/2012/03/salt.jpg)

These moisture phenomena directly impact structural behavior, material durability, and the expected performance of any future energy retrofit. Masonry with high moisture content exhibits increased thermal conductivity, reducing insulation efficiency and raising heating demand. Moreover, the presence of water promotes biological growth, from mold to algae and lichens, which further deteriorate surfaces and compromise indoor air quality. The review by Alfano et al. (2023) emphasizes that uncontrolled moisture "increases U-values, weakens the structure, damages the surfaces … and promotes growth of fungi and moulds"[58]. The authors also underline that proper diagnostic procedures are essential to discriminate between different moisture sources, as misidentification can lead to ineffective or even damaging interventions. For example, treating rising damp with impermeable coatings may trap interstitial condensation, while focusing only on rain penetration may overlook underlying capillary rise.

Therefore, in heritage contexts, moisture diagnosis and rehabilitation constitute the fundamental starting point for any comprehensive renovation plan. Without addressing these root causes, subsequent thermal improvements risk failure, loss of authenticity, or accelerated degradation of cultural property.

1.2. Why Moisture Control Must Precede Insulation

Introducing thermal insulation or airtight elements on damp masonry carries significant risks for both the structural fabric and the long-term performance of energy retrofits. When moisture remains untreated, any attempt to improve thermal resistance or airtightness can trap water inside the wall assembly, preventing natural drying and accelerating deterioration.

From a physical perspective, wet masonry has markedly higher thermal conductivity than dry materials. Laboratory measurements consistently show that even a modest increase in moisture content can double or triple thermal conductivity of brick or stone. As a result, the intended insulation performance is undermined, and the effective U-value of the wall rises instead of falling. Moreover, wet walls have higher heat capacity, which increases thermal inertia and may delay heating response, leading to occupant discomfort and higher energy bills.

The structural implications are equally serious. Water within pores undergoes volumetric expansion during freeze–thaw cycles, causing microcracking, spalling, and granular disintegration of bricks or stones. Repeated cycles can significantly reduce compressive strength. Ksit et al. (2022) report that elevated moisture not only raises energy demand but also directly reduces the load-bearing capacity of masonry, while simultaneously encouraging mold colonization and timber decay in adjacent elements[59].

In practice, if moisture is ignored, common retrofit actions may trigger failure mechanisms rather than improvements. For example:

[58] D'Ambrosio Alfano, Palella & Riccio, Moisture in Historical Buildings from Causes to the Application of Specific Diagnostic Methodologies, SSRN preprint, 2023, doi:10.2139/ssrn.4295738

[59] Ksit, Szymczak-Graczyk & Nazarewicz, Diagnostics and Renovation of Moisture Affected Historic Buildings, CEER 2022; DOI:10.2478/ceer-2022-0004

- Application of impermeable internal insulation can lead to interstitial condensation, blistering of plasters, and delamination of insulation boards.
- External insulation on damp façades may worsen rising damp, as evaporation paths are blocked, driving moisture further upward and into interior finishes.
- Installation of airtight windows and doors without managing existing wall dampness can trap humid air inside, resulting in surface condensation and mold growth.
- Hygroscopic salts already present in masonry are mobilized by retained moisture, migrating into new finishes and causing efflorescence or powdering.

Bernardo et al. (2024) emphasize in their critical analysis of European restoration practices that in many heritage projects failure to resolve rising damp prior to insulation consistently results in chronic failure of retrofit layers. Insulation systems detached prematurely, plasters disintegrated, and salt transport remained active, rendering the retrofit ineffective and costly[60]. Their findings underscore that neglecting moisture rehabilitation not only wastes investment but may aggravate heritage loss.

Beyond physical and structural concerns, uncontrolled dampness also poses risks to indoor environmental quality. Elevated humidity in heritage interiors promotes mold growth, which is linked to respiratory illnesses and occupant discomfort. Introducing insulation without prior moisture treatment can exacerbate these conditions, as trapped moisture accumulates in colder wall zones, stimulating fungal colonization. In protected buildings, where sensitive artworks or archives may be stored, this represents a direct threat to cultural assets.

From the perspective of conservation ethics, addressing moisture before insulation aligns with the principles of minimal intervention, reversibility, and material compatibility. Moisture rehabilitation often involves traditional methods—repairing drainage, reinstating lime-based renders, or introducing capillary breaks—that are fully compatible with heritage substrates. Conversely, energy retrofits typically rely on new materials that interact differently with moisture. If insulation precedes rehabilitation, incompatibilities are amplified, increasing the likelihood of irreversible damage to authentic materials.

Therefore, moisture rehabilitation is not simply an optional preparatory step; it is the foundation of any sustainable energy retrofit strategy in historic buildings. Only when masonry is dry, salt activity controlled, and vapor diffusion pathways secured can insulation, airtightness, or renewable energy technologies be responsibly implemented. Proper sequencing ensures that energy upgrades achieve their intended performance while preserving the authenticity, durability, and health of the heritage environment.

1.3. Compatible Methods of Moisture Rehabilitation for Protected Buildings

Because we deal with formally protected heritage buildings, moisture treatments must strictly respect the principles of compatibility, reversibility, and minimal intervention. The ultimate goal is to restore the building's ability to regulate moisture naturally, without introducing impermeable barriers that would compromise vapor permeability or accelerate hidden deterioration. Any intervention must therefore be carefully tailored to the material properties, historical value, and conservation requirements of the structure. Below are heritage-compatible approaches, expanded to illustrate their scope, opportunities, and limitations.

- Discreet drainage and base waterproofing: One of the most fundamental yet often overlooked measures is improving site hydrology and foundation-level drainage. Installing or repairing perimeter drains (French drains), ensuring correct slope of ground surfaces away from walls, and repairing gutters or downpipes can drastically reduce the moisture load reaching masonry foundations. In heritage

[60] Bernardo, Rinaldi & Guida, Critical Analysis of Restoration Practices Against Rising Damp (in press), TEMA journal

contexts, these interventions are minimally invasive and highly reversible, as they occur below ground and do not alter visible architectural fabric. In many Central European historic towns, poor urban drainage remains a primary cause of rising damp; thus, discreet drainage is frequently the most effective first step.



Figure 18 Discreet drainage

(source:https://encryptedtbn3.gstatic.com/images?q=tbn:ANd9GcRgfwg5zClwmWA6PYYdxPXY2njOlmU9hzoeHF8ICbf1cX1s7k6d_4GgFn3vTpdv)

- Installation or repair of damp-proof courses (DPC): When rising damp remains persistent, the creation of a horizontal moisture barrier may be considered. The most common solution in heritage practice involves chemical injections of hydrophobic fluids (e.g. silicone microemulsions) into the mortar joints to form a secondary DPC. However, as Szemiot, Hoła & Sadowski (2023) emphasize, the effectiveness of these injections in historic brick walls is uncertain, especially over the long term and in the presence of salts[61]. Drilling into historic walls also raises conservation concerns, and the introduction of synthetic chemicals may not be fully reversible. Consequently, chemical DPCs must be approached with caution, preceded by testing in non-critical zones and coupled with ongoing monitoring.



Figure 19 Repair of damp-proof courses (source:https://garrattsdamp.com/blog/the-guide-to-damp-proof-injection)

[61] Szemiot, Hoła & Sadowski, Assessment of the Effectiveness of Secondary Anti-Damp Insulation in Heritage Buildings Made of Historic Brick, Heritage Science 11:198 (2023), doi:10.1186/s40494-023-01043-x

- Electro-osmotic systems: These innovative systems establish a low electrical potential gradient across masonry walls to reverse capillary water movement. By driving water molecules downward, they counteract rising damp without introducing chemical substances. Koca et al. (2024) report on a case study in a historic building where electro-osmosis reduced moisture content from approximately 14.5% to 2.9% within nine months[62]. Electro-osmotic devices are particularly attractive in heritage settings as they are relatively non-invasive, can be reversed or removed, and do not alter the appearance of the building. However, their efficiency may vary depending on masonry conductivity and salt presence, and they require electrical power and maintenance.

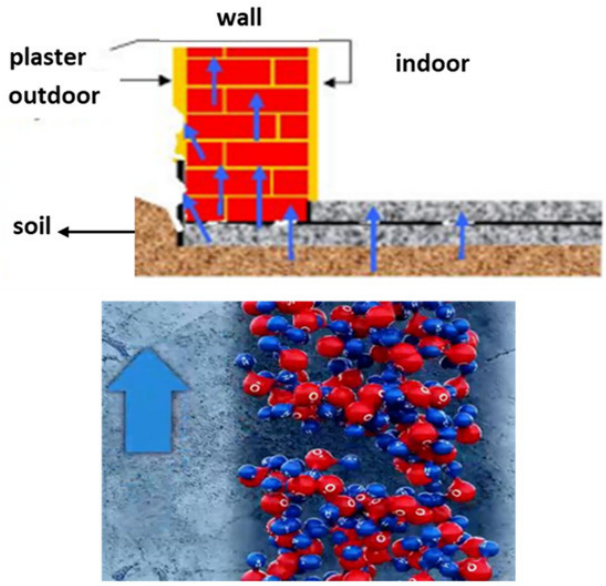


Figure 20 Electro-osmotic systems (source:Koca et al., Rising Damp Treatment in Historical Buildings by Electro-Osmosis, Buildings 14(5):1460 (2024), doi:10.3390/buildings14051460)

- Salt extraction and desalination: Moisture problems in heritage masonry are frequently aggravated by the presence of hygroscopic salts such as chlorides, nitrates, or sulfates. These compounds perpetuate dampness cycles by attracting atmospheric moisture, even at low relative humidity. Desalination techniques include poulticing with clay, cellulose, or sepiolite pastes that absorb salts as they crystallize out of the masonry during controlled drying. In severe cases, sacrificial renders—lime-based plasters intentionally designed to absorb salts and be periodically replaced—are used. Desalination is rarely a complete cure, but it significantly reduces salt concentrations, stabilizes surfaces, and prepares the walls for subsequent conservation and energy retrofitting.

[62] Koca et al., Rising Damp Treatment in Historical Buildings by Electro-Osmosis, Buildings 14(5):1460 (2024), doi:10.3390/buildings14051460



Figure 21 Trial cleaning of a detail on a 19th century cement stucco facade using ammonium carbonate in a clay and paper fibre poultice. (source: https://www.buildingconservation.com/articles/poultices/poultice.htm)

- Use of breathable lime-based renders and plasters: After moisture sources are reduced, surface protection plays a crucial role. Traditional lime plasters, lime-cement mixes, or modern mineral plasters with high vapor permeability allow the walls to "breathe" while providing a sacrificial protective layer against driving rain. In contrast, impermeable cement-based coatings, often applied in the 20th century, are incompatible with historic substrates and typically worsen dampness by trapping water. Reintroduction of lime renders not only respects historical authenticity but also facilitates gradual drying, salt migration to the plaster surface, and maintenance of indoor comfort.

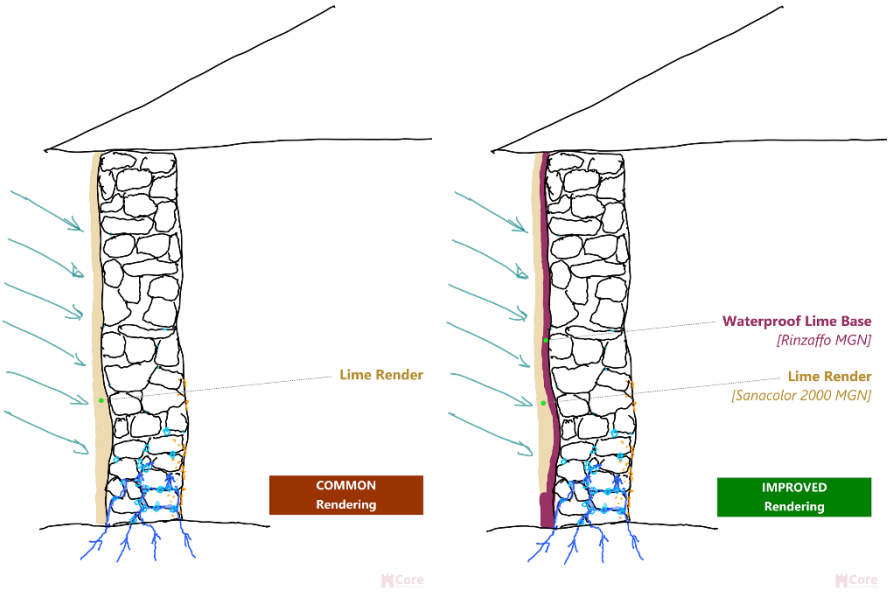


Figure 22 Use breathable lime-based renders and plasters (source:https://www.coreconservation.co.uk/solution/rendering-old-buildings/)

- Capillary-active insulation layers: In situations where energy retrofitting requires internal insulation, heritage-sensitive solutions employ capillary-active and vapor-permeable systems, such as calcium silicate boards, wood-fibre panels, or hygroscopic plasters. These materials buffer residual moisture, distribute it across a larger surface area, and allow evaporation rather than accumulation. Their application reduces the risk of interstitial condensation, which is one of the main hazards of internal insulation in historic buildings. However, successful performance depends on correct design (avoiding thermal bridges), skilled application, and continuous monitoring.

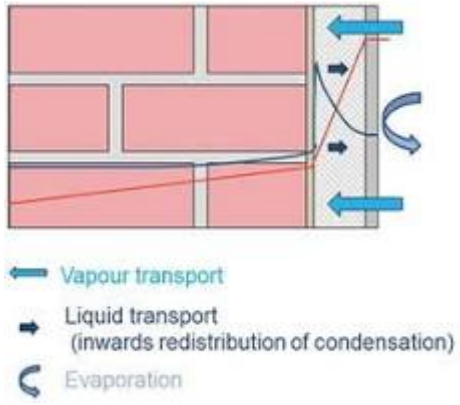


Figure 23 Capillary Active Interior Insulation Systems for Wall Retrofitting (source:https://www.tandfonline.com/doi/full/10.1080/15583058.2015.1009575)

- Monitoring and maintenance: No moisture treatment is effective without long-term monitoring. Hygrometric probes, non-destructive moisture sensors, and regular inspections allow conservation teams to evaluate the stability of interventions and detect emerging problems. In protected heritage contexts, monitoring also ensures compliance with conservation regulations and provides documentation for future interventions. Maintenance tasks—such as cleaning drainage channels, renewing lime washes, or replacing sacrificial renders—are essential to preserve the effectiveness of initial rehabilitation.

As Bernardo et al. (2024) emphasize, combining several of the above approaches in a holistic protocol is essential for long-term success; no single technique universally solves rising damp issues in historic fabric[63]. For example, improved drainage must often be combined with breathable lime renders, while electro-osmosis may need to be supported by salt extraction and monitoring. The sequence and combination of interventions must be tailored to the specific building, its materials, and conservation status.

In summary, heritage-compatible moisture treatments are characterized by non-invasiveness, compatibility with original materials, reversibility, and breathability. While modern engineering solutions exist, their adoption in cultural heritage requires caution, adaptation, and integration with traditional methods. Most importantly, these interventions must always be considered before any thermal retrofitting takes place, ensuring that the cultural asset remains structurally sound, aesthetically authentic, and capable of accommodating energy efficiency upgrades without risk of damage.

1.4. Recommended Sequence of Intervention

Moisture rehabilitation in formally protected heritage buildings cannot be a single action; it requires a systematic and phased approach that combines diagnostic precision, targeted interventions, and long-term monitoring. Each phase builds on the previous one, ensuring that the building is progressively stabilized before any thermal upgrades are introduced. The following expanded workflow illustrates the recommended sequence in detail.

The first stage involves a comprehensive investigation to understand the type, extent, and sources of moisture.

- Non-destructive diagnostic tools include infrared thermography (to detect thermal anomalies and hidden damp areas), electrical resistance or capacitance moisture meters (to map surface and subsurface dampness), and hygrometric probes.

[63] Bernardo, Rinaldi & Guida, Critical Analysis of Restoration Practices Against Rising Damp, TEMA (in press)

- Salt mapping is crucial, since hygroscopic salts strongly influence moisture behavior. Portable X-ray fluorescence (XRF) or ion chromatography may be used to identify chloride, nitrate, and sulfate distribution.
- Endoscopy and borescope inspection allow visualization of inner wall cavities, voids, or failures in old damp-proof courses.
- Archival and historical research should accompany technical tests, as construction phases, past interventions, or earlier flooding events may explain current problems.
  The outcome of this stage should be a diagnostic report documenting all sources of dampness and providing a baseline against which later improvements will be measured.

After diagnosis, the next step is to stop the ingress of water at its origin.

- Surface drainage: Adjust ground levels and slopes around the building to direct rainwater away from foundations. Install or repair French drains or gravel trenches to intercept groundwater.
- Rainwater management: Clean and repair gutters, downpipes, and roof coverings; blockages are often underestimated causes of wall saturation.
- Plumbing repairs: Replace corroded pipes, leaking joints, or sanitary fixtures that contribute to localized damp.
- Groundwater control: Where groundwater levels are high, sub-surface drainage systems or sump pumps may be needed.
  The guiding principle is that removing water sources is always more effective than attempting to block water inside the wall.

Once sources are controlled, the building must be allowed to dry gradually.

- Natural drying (ventilation and heating) is preferred in heritage buildings to avoid stress on fragile materials. Forced drying should be applied cautiously, using low-temperature air movement rather than high-heat blowers.
- Desalination: Where salts are present, apply poultices of clay, cellulose, or sepiolite to draw salts out. Multiple applications may be required.
- Sacrificial renders (lime-based, vapor-open plasters) can be applied temporarily to absorb salts, then removed and replaced. The aim is to lower equilibrium moisture content and reduce salt concentrations to levels that no longer drive deterioration.

In some cases, secondary damp-proofing may be necessary to stop capillary rise:

- Chemical injection barriers (silane/siloxane fluids, microemulsions) can be introduced into mortar joints to create a hydrophobic course. Effectiveness depends on masonry porosity and must be tested on pilot areas.
- Electro-osmotic systems use low electrical currents to repel water molecules downward. These are non-invasive and reversible but require monitoring of performance and energy supply.
- Physical insertion of barriers (stainless steel or plastic membranes) may be considered in extreme cases, but this is highly invasive and rarely acceptable in heritage contexts.
  Because of conservation concerns, these measures are justified only when diagnostics confirm persistent rising damp that cannot be solved by drainage and drying alone.

Once walls are stabilized, surfaces should be protected with materials that allow vapor diffusion while resisting liquid water ingress.

- Lime plasters and lime washes are the most traditional and compatible options, ensuring reversibility and breathability.

- Mineral renders with hydrophobic properties may be used where higher water resistance is needed, provided they remain vapor-open.
- Internal insulation systems must be carefully chosen: capillary-active boards (e.g. calcium silicate, wood-fibre) are preferable to impermeable foams, which risk condensation.
  Breathable finishes act as a buffer layer, enabling the wall to manage residual moisture and preventing damage to both structure and surface decoration.

Moisture rehabilitation does not end with construction; it requires a long-term monitoring plan:

- Sensors and dataloggers should measure wall moisture, relative humidity, and temperature over at least one seasonal cycle.
- Visual inspections for efflorescence, plaster deterioration, or mold growth must be conducted regularly.
- Threshold criteria (e.g. stable, material-specific moisture levels defined by the specialist, absence of new salt efflorescence) should be defined to determine readiness for energy retrofitting.
  Only when measurements show stable and safe moisture levels over time should thermal insulation, airtightness improvements, or other retrofit actions proceed.

In conclusion, for historically protected buildings in Central Europe, moisture rehabilitation is an indispensable preliminary stage before energy modernization. Each step—diagnosis, source control, drying, optional damp-proofing, application of vapor-open finishes, and long-term monitoring—must be implemented systematically and in line with conservation principles. By following this phased approach, subsequent insulation and energy efficiency measures will be durable, effective, and respectful of the building's historic integrity, ensuring that cultural heritage is preserved while enabling its sustainable use for future generations.

.

2. Increasing the thermal protection of the heated space envelope

- External Walls (Solid Masonry)

In many protected buildings, the façade must remain untouched; thus, **internal insulation** is the predominant option. The EU-funded RIBuild project has developed guidelines for internal insulation in historic buildings, emphasizing risks of condensation, mold, and moisture accumulation if improperly designed[64]. According to the RIBuild approach, internal insulation should be selected and dimensioned based on hygrothermal simulation, material properties, and orientation (risk of mold assessed probabilistically).

A promising material family is **wood-fibre insulation systems**, which combine moderate thermal resistance with high moisture buffering. Marincioni & Altamirano-Medina (2023) document long-term monitoring of two solid-wall buildings insulated with wood-fibre systems; they found that moisture behavior and mold risk could be managed with careful design, proper material selection, and attention to orientation and interface detailing[65]. Another cautionary result is found in the Leuven case study: walls with **vapour-tight insulation** showed more moisture risk, while **capillary-active insulation** behaved more like uninsulated walls and exhibited better moisture safety under climate change scenarios[66].

In Vienna, a retrofit system using **wood-fibre boards** internal insulation was developed under the WHISCERS™ concept. The boards were CNC-cut to conform to irregular masonry, and both simulation and monitoring showed acceptable moisture performance—no condensation risk under typical climate conditions[67].

In solid-wall retrofits, prefer **thin, capillary-active insulation** rather than thick rigid foam. Avoid impermeable vapor barriers, which can trap interstitial moisture and cause long-term damage. Always ensure good detailing at reveals, junctions with existing plaster, and base levels.

- Roofs and Ceilings

Roof and attic retrofit is often less constrained by external appearance, thus offering more options. Yuk *et al.* (2023) studied a historic building with exposed rafters and found that careful insulation design can lead to significant energy gains without damaging timber structures[68].

In practice:

- For **attic ceilings (cold roofs)**, install breathable insulation between ceiling joists (e.g., wood-fibre, hemp) and underpin with a vapor-open membrane or lime plaster layer to prevent warm air reaching cold surfaces.
- For **warm roofs** (insulation above rafters), use wood-fibre or insect-resistant natural materials above and below rafters. Maintain ventilation above the insulation layer and avoid impermeable membranes.
- Roof junctions, flashings, and eaves must be detailed to prevent rain ingress and to allow moisture release.

---

[64] E. J. de Place Hansen, E. B. Møller & M. Ørsager, *Guidelines for Internal Insulation of Historic Buildings*, in: 12th Nordic Symposium on Building Physics (NSB 2020), E3S Web Conf. 172, Article 01004 (2020), https://doi.org/10.1051/e3sconf/202017201004

[65] V. Marincioni & H. Altamirano-Medina, *The Behaviour of Wood Fibre Insulation Systems for Solid Wall Buildings: Lessons from a Long-term Monitoring Study*, J. Phys. Conf. Ser. 2023, doi:10.1088/1742-6596/2654/1/012127

[66] X. Dang et al., "Hygrothermal Response of Masonry Facades with Vapour-Tight vs Capillary-Active Insulation Systems", *Built Heritage* 9, Article 188 (2025), https://doi.org/10.1186/s43238-025-00188-x

[67] J. Nackler, K. Pascha & W. Winter, *Developing an Internal Insulation System Made of Wood-Fibre Boards for Energy-Efficient Retrofitting of Heritage Buildings in Vienna*, SET 2014 conference, DOI:10.13140/2.1.4925.2483

[68] H. Yuk et al., "Historic Building Energy Conservation with Wooden Attic Insulation", *Energy and Buildings* 293 (2023), article 113120, https://doi.org/10.1016/j.enbuild.2023.113120

Throughout, avoid spray-foam or closed-cell materials that block vapor; historical timber and masonry systems require breathable layers to manage residual moisture.

- Floors

Floor insulation depends on construction type:

- For **suspended timber floors**, if access exists from below (crawl space), install breathable insulation (sheep wool, hemp, wood-fibre) between joists and seal air gaps. If ceilings below are intact and original, only insulate during renovation if removal is acceptable.
- For **solid ground floors**, insulation under the slab or above it is possible only when floors are being rebuilt. Otherwise, use removable insulated flooring, rugs or planks to reduce heat loss without disturbing the masonry. Avoid raising interior soil levels, which can worsen rising damp.

Any insulation must not obstruct existing damp-proof courses or trap moisture in masonry.

- Windows and Doors

These are critical weak points in the envelope:

- **Retain and repair original timber frames**: seal gaps with reversible brush or pile seals; consolidate joints; reglaze using slim, low-e glass if acceptable.
- Use **secondary glazing systems**: a slim, internal glazed pane mounted behind the historic sash preserves facade while greatly improving thermal performance.
- **Interior shutters or thermal curtains**: heavyweight shutters or curtains applied daily can reduce heat loss nearly as effectively as double-glazing in many circumstances.
- **Door thresholds and seals**: add neoprene or brush seals; if appropriate, install a reversible storm door. Care must be taken not to damage the original door leaf.

Design Principles and Implementation Guidance:

- **Minimize insulation thickness** to preserve profile of cornices, reveals and decorative elements.
- Use **vapour-open, hygroscopic materials** (lime-based plasters, natural fibre boards) that buffer moisture rather than block it.
- **Detail interfaces carefully**: at floor-slab, wall-ceiling and wall-window junctions to avoid thermal bridges or moisture traps.
- Always apply **reversible fixings** (clips, screws in mortar joints, or non-invasive adhesives) so future removal is possible.
- Perform **hygrothermal simulations** (e.g. WUFI, DELPHIN) before implementation to assess mold risk, condensation and thermal performance ahead of construction, as recommended in RIBuild guidelines[69].
- Monitor moisture and RH post-retrofit to validate performance and detect issues.

3. Improving the energy efficiency of existing or installing new technical systems in a building

[69] E. J. de Place Hansen et al., *Guidelines for Internal Insulation…*, E3S Web Conf. 172 (2020), https://doi.org/10.1051/e3sconf/202017201004

Improving the energy efficiency of technical systems in heritage buildings requires balancing energy savings with conservation of historical values. Standards such as EN 16883:2017 call for integrated, multi-criteria approaches – typically involving interdisciplinary teams of conservators, engineers, and stakeholders. Every retrofit begins with a thorough survey, archival research, and technical inspections (including thermography) as well as monitoring of indoor climate. Energy simulations (e.g., EnergyPlus, IDA ICE) integrate utility data with building parameters to establish baselines and test interventions[70].

The selection of measures follows assessment of technical compatibility with historic fabric, energy efficiency, economic viability (LCC), and environmental impact (LCA). Interventions must remain reversible, respect the building's character, and maintain indoor environmental quality according to ISO 17772-1. For museums or archives, this often requires adaptive temperature setpoints (18–22 °C) to protect collections.

3.1. Heating and Domestic Hot Water (DHW) Systems

Many heritage buildings still rely on inefficient fossil fuel boilers, such as outdated oil or coal-fired systems, which are highly energy intensive and incompatible with modern climate goals. Energy savings can be achieved through zoning of large spaces, optimized heating schedules, and conservation heating strategies that prioritize relative humidity stability over temperature, preventing condensation and mold while maintaining acceptable comfort levels. Advanced control systems with sensors can dynamically adjust heating supply in response to real-time humidity and occupancy.

Recommended upgrades include the installation of biomass boilers or high-efficiency heat pumps, which are often chosen for their compatibility with heritage constraints when carefully integrated. Biomass systems, especially pellet boilers, can achieve efficiencies above 90% while using renewable fuel. Heat pumps, whether air-to-water, water-to-water, or ground-source, are increasingly common due to their high seasonal efficiency. For example, in a Cypriot retrofit, air-to-brine heat pumps integrated with envelope improvements achieved a seasonal coefficient of performance (SCOP) of 4.46, reducing heating demand significantly[71]. In addition, hybrid solutions combining heat pumps with existing boilers can allow a gradual transition and ensure resilience during extreme conditions; in a zero-emission perspective, however, fossil-fuel boilers should be treated only as a temporary back-up with a clear phase-out plan.

Centralized DHW systems with well-insulated piping and large buffer tanks reduce distribution and standby losses. The application of thermostatic mixing valves and low-flow fixtures can further reduce consumption. Solar thermal collectors, when installed on non-visible roof areas or secondary buildings, can supplement DHW production in line with conservation requirements, covering a significant fraction of hot water demand during summer months. In some cases, waste heat recovery from ventilation or process equipment can also preheat DHW, maximizing system efficiency.

Combined upgrades to heating and DHW can reduce primary energy consumption by 40–60% compared to pre-retrofit levels [Thravalou S., Michopoulos A., Alexandrou K., Artopoulos G., *Energy retrofit strategies of built heritage: using Building Information Modelling tools for streamlined energy and economic analysis*, IOP Conference Series: Earth and Environmental Science, 1196, 012115, 2023, doi:10.1088/1755-1315/1196/1/012115]. Furthermore, these interventions contribute to improved indoor climate stability, reduced CO2 emissions, and greater resilience of heritage assets, provided that they are designed to be reversible and minimally intrusive to the historic fabric.

---

[70] Leijonhufvud G., Broström T., Eriksson P., Troi A., *Planning Energy Retrofits of Historic Buildings: EN 16883:2017 in Practice*, IEA SHC Task 59 | EBC Annex 76: Renovating Historic Buildings Towards Zero Energy, 2021, available at: https://www.iea-shc.org/Data/Sites/1/publications/D.B3--Handbook.pdf

[71] Thravalou S., Michopoulos A., Alexandrou K., Artopoulos G., *Energy retrofit strategies of built heritage: using Building Information Modelling tools for streamlined energy and economic analysis*, IOP Conference Series: Earth and Environmental Science, 1196, 012115, 2023, doi:10.1088/1755-1315/1196/1/012115

3.2. Cooling Systems

Cooling historic buildings is difficult due to high thermal mass, limited insulation, and the need to preserve sensitive interiors. Excessive heat gains during summer can persist well into the night, creating discomfort and risk to collections. Variable refrigerant flow (VRF) systems are among the most promising solutions, as they provide zoned climate control, high efficiency, and minimal invasiveness. In a 1933 museum case study, VRF reduced annual cooling demand by around 50% and improved thermal comfort by lowering the predicted mean vote (PMV) index by up to 31%[72]. Further advantages of VRF include the ability to conceal small ducts in attics or floors, avoiding visual disturbance, and their flexibility in serving irregular historic layouts. When selecting refrigerant-based systems, the EU rules on fluorinated gases should be taken into account, giving preference to low-GWP or natural refrigerants and to compact systems that limit refrigerant pipework in historic interiors.

Passive measures such as external shading (awnings, shutters, pergolas), ventilated façades, or ground-air heat exchangers can complement active cooling. These reduce peak loads and limit mechanical system size, thereby lowering visual and material impact. Other traditional strategies, such as nighttime natural ventilation and the use of high thermal mass surfaces, can also play a role if carefully managed. Hygrothermal simulations are essential to evaluate condensation risk, especially when adding insulation or introducing cold air into massive masonry walls. Case studies demonstrate that retrofit packages combining passive shading, careful window management, and VRF have proven compatible with conservation standards and achieved significant energy savings[73].

3.3. Ventilation Systems

Traditional natural ventilation is inadequate in sealed retrofitted envelopes. Heat recovery ventilation (HRV) or demand-controlled ventilation (DCV) systems can recover 70–90% of thermal energy while ensuring air quality. Decentralized room-based HRV units are well suited for heritage contexts, as shown in Tyrolean farmhouses where air distribution exploited existing smoke chambers[74].

Decision-support tools such as HiBERtool guide appropriate choices depending on airtightness and room height. Enhanced natural ventilation remains viable in low-use spaces, potentially reducing ventilation energy demand by 20–40%[75].

3.4. Lighting Systems

Lighting retrofits should focus on replacing incandescent or fluorescent lamps with LEDs, which reduce electricity consumption by 70–80%. In a Tuscan cultural landscape, LED retrofits improved uniformity of illuminance while reducing CO2 emissions [Valetti L., Floris F., Pellegrino A., *Renovation of Public Lighting Systems in Cultural Landscapes: Lighting and Energy Performance and Their Impact on Nightscapes*, Energies, 14(2), 509, 2021, doi:10.3390/en14020509]. Beyond simple replacement, lighting designers must consider spectral quality of light: warmer color temperatures (2700–3000 K) are usually more compatible with historic façades, while high CRI (color rendering index) LEDs highlight architectural details faithfully

[72] Aljundi K., Rodrigues L., *Assessing strategies for retrofitting cooling systems in historical buildings*, Energy Reports, 11, 150-158, 2024, doi:10.1016/j.egyr.2023.11.048

[73] Aljundi K., Rodrigues L., *Assessing strategies for retrofitting cooling systems in historical buildings*, Energy Reports, 11, 150-158, 2024, doi:10.1016/j.egyr.2023.11.048

[74] Rieser A., Pfluger R., Troi A., Herrera-Avellanosa D., Thomsen K.E., Rose J., Arsan Z.D., Akkurt G.G., Kopeinig G., Guyot G., et al., *Integration of Energy-Efficient Ventilation Systems in Historic Buildings—Review and Proposal of a Systematic Intervention Approach*, Sustainability, 13(4), 2325, 2021, doi:10.3390/su13042325

[75] Rieser A., Pfluger R., Troi A., Herrera-Avellanosa D., Thomsen K.E., Rose J., Arsan Z.D., Akkurt G.G., Kopeinig G., Guyot G., et al., *Integration of Energy-Efficient Ventilation Systems in Historic Buildings—Review and Proposal of a Systematic Intervention Approach*, Sustainability, 13(4), 2325, 2021, doi:10.3390/su13042325

without distorting materials. The ability to adjust intensity dynamically helps to respect both human comfort and cultural landscape aesthetics.

Smart controls (motion sensors, daylight dimming, astronomical timers) can optimize usage in intermittently occupied spaces. In museums, libraries, and churches, sensors prevent unnecessary lighting of unoccupied zones, extending lamp life and reducing maintenance. In outdoor heritage areas, astronomical timers adjust illumination schedules to seasonal changes in daylight, preserving nightscapes. BIM-based lighting analysis ensures preservation of heritage ambiance by simulating different scenarios before interventions are carried out. Careful luminance design avoids over-illumination that would alter the nightscape, with specific guidelines recommending luminance ratios that maintain visual hierarchy between monuments and their surroundings[76].

Additional strategies include integrating lighting into architectural elements discreetly, using recessed fixtures or historically styled lanterns that conceal modern sources. Dimming protocols, staged lighting, and adaptive façade lighting can emphasize heritage features without excessive energy use. For sensitive sites, light pollution and ecological impact must also be considered: minimizing upward light prevents skyglow and protects nocturnal wildlife. Thus, comprehensive lighting retrofits in cultural heritage contexts combine LED efficiency, adaptive controls, detailed simulation, and conservation-compatible aesthetics to achieve energy savings of 70–85% while preserving the authenticity of nightscapes.

3.5. Renewable Energy Sources (RES) in Technical Systems

RES integration must prioritize minimal visual impact and reversibility. Photovoltaic (PV) panels, when carefully positioned on hidden or secondary roof slopes, can cover a meaningful share of a building's electricity demand while maintaining architectural integrity. Case studies show that visually non-intrusive PV systems can be integrated without altering rooflines or damaging historic tiles, provided they are mounted on removable substructures. In a Cypriot heritage retrofit, a 10.88 kWp PV system combined with heat pumps reduced primary energy demand by 77.8%[77].

Geothermal systems represent another important option, provided archaeological layers are respected. Vertical or horizontal ground-source heat exchangers can deliver high efficiency in heating and cooling, but feasibility studies must assess soil conditions, groundwater levels, and the risk of disturbing buried heritage. Low-depth geothermal probes and reversible ground-source heat pumps have been successfully demonstrated in urban heritage sites, delivering seasonal efficiencies (SCOP/SEER) exceeding 4.0.

Solar thermal collectors, particularly vacuum-tube models, can supply most domestic hot water (DHW) demand in summer. Their placement should prioritize non-visible surfaces or adjacent auxiliary structures. In Mediterranean climates, coverage can exceed 70% of annual DHW load, while in colder Central European climates, they serve as effective preheating systems integrated with biomass or conventional boilers.

Biomass systems, especially pellet or woodchip boilers, are considered heritage-compatible when located in ancillary spaces such as basements or service buildings. They achieve over 90% efficiency, and when combined with modern flue gas cleaning systems, they can reduce particulate emissions. Integration with district heating networks based on biomass also offers a communal solution for cultural heritage neighborhoods. In dense historic centres, however, local air quality, fuel delivery and storage space must be assessed carefully; biomass is therefore usually more suitable for central or district plants outside the protected core than for individual boilers in each building.

---

[76] Valetti L., Floris F., Pellegrino A., *Renovation of Public Lighting Systems in Cultural Landscapes: Lighting and Energy Performance and Their Impact on Nightscapes*, Energies, 14(2), 509, 2021, doi:10.3390/en14020509

[77] Thravalou S., Michopoulos A., Alexandrou K., Artopoulos G., *Energy retrofit strategies of built heritage: using Building Information Modelling tools for streamlined energy and economic analysis*, IOP Conference Series: Earth and Environmental Science, 1196, 012115, 2023, doi:10.1088/1755-1315/1196/1/012115

Hybrid renewable systems combining PV, solar thermal, biomass, and heat pumps have shown the ability to cover 40–60% of annual energy demand in heritage buildings[78]. Such systems are most effective when designed as packages, maximizing synergies between technologies. For instance, PV-generated electricity can power heat pumps, while solar thermal reduces DHW demand, and biomass provides backup during peak loads.

Life cycle assessment (LCA) is essential to ensure that embodied energy and environmental impact are minimized. Materials should be chosen for recyclability, low CO_2 footprint, and ease of dismantling. Reversibility must be guaranteed, for example, by mounting PV panels on removable frames, using non-invasive fixings for solar thermal collectors, or siting biomass boilers in independent structures. Monitoring systems should be installed to track performance and provide evidence of energy savings without compromising heritage value.

Ultimately, well-integrated RES strategies can allow heritage buildings to approach nearly zero-energy building (NZEB) standards while safeguarding historic integrity, ensuring both cultural preservation and long-term sustainability.

E. RECAPITULATION OF THE COMBINATION OF MEASURES TO INCREASE ENERGY EFFICIENCY OF THE BUILDINGS

Heritage-sensitive retrofits require a holistic approach that begins with preservation of the building fabric. The first and fundamental step is **moisture diagnostics and control**: all sources of water ingress or dampness must be identified and remediated before thermal upgrades are applied. Uncontrolled moisture accelerates decay (mould, rot, corrosion) and can make insulation counter-productive. For example, the U.S. National Park Service notes the importance of “careful diagnosis” and managing moisture thoroughly before installing any new systems. Likewise, Historic England warns that energy efficiency measures may trap moisture in the fabric unless adequate ventilation and hygrothermal analysis are provided. In practice, this means carrying out a full condition survey (including drainage, roof and gutter repairs) and only proceeding to insulation once the building is dry and watertight[79,80].

- Thermal Envelope Protection

Once moisture risks are addressed, the building envelope is upgraded with conservation-compatible insulation and glazing. In practice this often means internal insulation (e.g. vapour-open aerogel boards or insulating plaster) or external insulation on non-significant facades, plus improvements to the roof and basement. The EFFESUS project found that thin internal aerogel layers (injected behind plaster or panelling) can reduce wall heat transfer by two-thirds without harming original surfaces[81]. Special mortars (e.g. lime-based, aerogel-enhanced or perlite-lime fills) are suitable for uneven historic walls and have passed driving-rain and freeze-thaw tests[8283]. Windows and doors are treated sensitively: instead of wholesale replacement, secondary glazing or slim-line double glazing preserves frames while cutting heat loss[8485]. Roofs and attics

[78] de Santoli L., Garcia D.A., Groppi D., Belloni E., Palumbo M., Toschi L., *Integration of renewable technologies in historical and heritage buildings: A review*, Energy and Buildings, 177, 96-111, 2018, doi:10.1016/j.enbuild.2018.07.058

[79] https://historicengland.org.uk/advice/technical-advice/retrofit-and-energy-efficiency-in-historic-buildings/improving-energy-efficiency-through-mitigation/risks-of-energy-efficiency-interventions/

[80] https://www.nps.gov/orgs/1739/upload/preservation-brief-39-controlling-moisture.pdf

[81] https://cordis.europa.eu/project/id/314678/reporting

[82] https://cordis.europa.eu/project/id/314678/reporting

[83] https://cordis.europa.eu/project/id/314678/reporting

[84] https://www.mdpi.com/2071-1050/17/7/3002

[85] https://cordis.europa.eu/project/id/314678/reporting

are insulated (above ceilings or between rafters) to reduce winter heat loss, and vapor-permeable insulation is used to avoid trapping moisture. In all cases the retrofit criteria go beyond U-values: interventions must be reversible, conserve original materials, and respect aesthetics[86][87]. For example, EFFESUS guidance stresses that any envelope upgrade should preserve the appearance of façade and fabric – even thin internal insulation must be chosen to avoid visible bulking and allow traditional materials.

- Building Services Upgrades

With the envelope improved, the next focus is on **mechanical and electrical systems**. Heating and hot-water plant are replaced with high-efficiency equipment: preferably heat pumps sized to the reduced heat demand or connection to low-carbon district heating, with fossil-fuel boilers used only as a transitional solution. Where available, connections to district heating networks or communal biomass systems are considered. Domestic hot-water tanks and pipes are insulated, and controls (timers, thermostats, TRVs) are modernized to avoid overheating or standby losses[88]. Ventilation is crucial: increased airtightness and the desire for thermal comfort usually require installing controlled fresh-air systems (mechanical ventilation with heat recovery or hybrid systems) to maintain air quality and humidity. In fact, Historic England advises that *"a ventilation strategy to eliminate pollutants and regulate indoor temperature and humidity levels will always be needed"* in energy retrofits[89][90] .

Lighting and electrical loads are also addressed. Traditional incandescent and halogen lamps are replaced by LEDs with occupancy and daylight sensors, cutting lighting energy by over 50% in many cases[91][92]. Ventilation fans, pumps, and appliances are downsized to efficient models. In summer or warm zones, passive cooling (shading devices, green façades or reflective roof coatings) is added: for example, EFFESUS developed high-reflectance coatings that can be applied to walls or roofs to reduce solar heat gain and cooling demand without altering historic fabric. In all systems, advanced controls and automation are used where possible: retrofitting smart thermostats, zoning, and building management systems has proven very cost-effective in heritage projects. Indeed, one EFFESUS case study noted that "upgrading the control systems to reduce use and ensure comfortable conditions is very cost effective"[93][94]. As a complement, occupant behavior is addressed via education and easy-to-use controls, yielding further (no-cost) savings.

Renewable Energy Integration

After demand is minimized, on-site renewables are integrated. Because historic districts may have visual or conservation constraints, technologies are chosen and placed carefully. Photovoltaic panels can be roof-mounted or building-integrated where sightlines permit; solar thermal or ground-source heat pumps can supply hot water; and local biomass (e.g. woodchip boilers or biogas from waste) can serve district heating loops. Crucially, most guidance (e.g. Historic England) emphasizes doing all feasible "reduce demand" measures before adding renewables. This minimizes system size, cost and heritage impact. For example, conservation advice notes that LZC (low/zero carbon) installations should only follow once insulation,

[86] https://cordis.europa.eu/project/id/314678/reporting

[87] https://historicengland.org.uk/advice/technical-advice/retrofit-and-energy-efficiency-in-historic-buildings/improving-energy-efficiency-through-mitigation/

[88] https://www.mdpi.com/2071-1050/17/7/3002

[89] https://historicengland.org.uk/advice/technical-advice/retrofit-and-energy-efficiency-in-historic-buildings/improving-energy-efficiency-through-mitigation/risks-of-energy-efficiency-interventions/

[90] https://historicengland.org.uk/advice/technical-advice/retrofit-and-energy-efficiency-in-historic-buildings/improving-energy-efficiency-through-mitigation/risks-of-energy-efficiency-interventions/

[91] https://www.mdpi.com/2071-1050/17/7/3002

[92] https://www.mdpi.com/2071-1050/17/7/3002

[93] https://cordis.europa.eu/project/id/314678/reporting

[94] https://cordis.europa.eu/project/id/314678/reporting

efficient glazing and services are in place[95][96]. In district-wide projects, EFFESUS demonstrated creative renewable schemes: supplying on-site heat pumps from the local grid to hide units in roofs/basements, or piping locally produced biogas through street conduits. These examples show that even in protected areas, flexible solutions (small-scale PV, buried biomass, smart grid connections) can achieve net-zero targets when paired with deep efficiency gains.

Mobility and Accessibility Measures

Energy planning in historic neighbourhoods can also address transport and access. While most interventions target buildings, district-level mobility strategies (pedestrianization, cycle lanes, electric transit) reduce overall emissions and improve livability. For instance, restricting heavy vehicle access in old town centres and providing nearby EV charging lowers combustion emissions without physical intervention on the buildings. Likewise, improving sidewalks, wayfinding and universal accessibility encourages walking and use of public transport. These measures complement building retrofits by reducing energy use and pollution at the urban scale. In essence, an integrated plan treats the historic district as an "urban ecosystem"[97]: energy-efficiency retrofits are implemented alongside traffic calming, green transport incentives and accessibility improvements to achieve broader sustainability goals.

Typical Sequences and Phasing of Measures

In practice, retrofit measures are implemented in logical phases. A common sequence is:

- Preliminary assessment and moisture control. Begin with a detailed heritage and technical survey (including thermography, blower-door tests, moisture monitoring) and fix any leaks or drainage issues.
- Envelope interventions. Next, add insulation to walls, roofs and floors (using moisture-compatible materials) and upgrade glazing/seals. This reduces heating demand while preserving historic character.
- Services upgrades. Then install or replace heating, cooling, ventilation and lighting systems with high-efficiency equipment and controls (e.g. heat pumps, heat-recovery ventilation, LEDs).
- Renewable deployment. Finally, add renewable energy sources sized to the reduced load (PV arrays, solar collectors, local bioenergy).

This staged approach avoids unintended damage – for example, insulation is only applied after the fabric is stable and moisture-managed. Historic England likewise recommends installing insulation only after risk-based design, since improper insulation "can make a building less energy efficient" or harm occupants and fabric. In sum, the phasing typically follows diagnosis & repair → fabric upgrades → system upgrades → renewables, with quality checks at each stage.

Exemplary Retrofit Combinations by Building Type

Different building typologies in historic districts require tailored packages of measures:

Historic tenement (multi-family apartment). A Central European masonry tenement might be retrofitted by insulating the external walls from the inside where the façade is protected (using a breathable, capillary-active system), insulating the attic or roof, and upgrading or repairing windows with slim double-glazing or secondary glazing. Heating could shift from old boilers to a district hot-water network or communal heat pumps. LED lighting and smart thermostats are installed in each dwelling. In one EFFESUS case, blown-in

[95] https://historicengland.org.uk/advice/technical-advice/retrofit-and-energy-efficiency-in-historic-buildings/improving-energy-efficiency-through-mitigation/

[96] https://historicengland.org.uk/advice/technical-advice/retrofit-and-energy-efficiency-in-historic-buildings/improving-energy-efficiency-through-mitigation/risks-of-energy-efficiency-interventions/

[97] https://cordis.europa.eu/project/id/314678/reporting

aerogel behind plaster in a Scottish tenement was used to insulate walls without altering décor[9899]. This, combined with secondary glazing and radiator efficiency measures, can substantially reduce space-heating demand[100101].

Public or institutional building. A municipal library or school often has high occupancy and strict comfort needs. For such buildings, external insulation (on rear or side walls) may be possible where allowed; otherwise, inside insulation plus significant roof insulation is applied. Original sash windows are preserved but fitted with interior drafts and thin double glazing. The heating plant is replaced with a ground-source or air-source heat pump sized for peak load, and a balanced mechanical ventilation system with heat recovery ensures good air quality. Lighting is fully LED with daylight controls (which alone can cut lighting demand by 70%[102103]). Building controls are modernized on a digital BMS. If the site allows, solar panels or a rooftop green roof are added post-retrofit to meet remaining electricity and DHW demand.

Ecclesiastical structure (church or chapel). Historic churches typically have vast volumes, uninsulated roofs, and large, delicate windows. Insulating interventions focus on non-intrusive areas: for example, insulating beneath an unoccupied gallery floor or in the attic above the ceiling. High-performance secondary glazing can be added to stained glass windows, or external shutters installed seasonally to reduce heat loss and glare. Conservation heating (low-power RH control) ensures the masonry and artworks are kept dry. LED retrofits of interior lighting often yield large gains given the intensity of lighting loads for heritage spaces. External solar shading (awnings or plantings) is used to mitigate summer overheating. Small renewable systems (e.g. discreet PV panels on a rear roof or an air-source heat pump hidden at ground level) supply the modest heating and power needs. For instance, in hot climates, applying a radiant-reflective roof coating can reduce solar gain and cooling demand without altering the historic appearance[104105].

These examples illustrate the multi-faceted approach needed: envelope work is combined with systems work and renewables in each case, with specific care to heritage. In Central/Eastern Europe's cold winters, the emphasis is on insulation and heating efficiency, whereas in Southern Europe's hot summers, priority may shift to solar shading, natural ventilation and reflective coatings. Nonetheless, in every context the retrofit must be designed within the prevailing heritage constraints and local climate.

Standards and Guidelines (EN 16883:2017 and ISO 17772-1:2017)

European and international standards provide frameworks to ensure compatibility of retrofit measures. Notably, EN 16883:2017 (Conservation of cultural heritage – Guidelines for improving the energy performance of historic buildings) prescribes a systematic, multi-step planning process. It requires assessment of heritage significance, whole-building energy analysis, and multidisciplinary decision-making so that energy interventions are balanced against conservation values. The standard has been widely endorsed (e.g. by IEA and HUL projects) as a means to "lower energy use without compromising heritage values". Concurrently, ISO 17772-1:2017 (Energy performance of buildings – Indoor environmental quality – Part 1) defines target indoor conditions (thermal comfort ranges, ventilation rates, lighting levels, etc.) for building design and retrofit. In practice, this means any retrofit must both improve energy use and maintain acceptable indoor climate. For example, EN 16883 guides the qualitative assessment of measure impacts (ensuring reversibility and minimal visual impact), while ISO 17772-1 (together with EN 16798-1, which replaced EN 15251) provides numerical thresholds to verify that, say, heating upgrades deliver comfort or

[98] https://cordis.europa.eu/project/id/314678/reporting
[99] https://cordis.europa.eu/project/id/314678/reporting
[100] https://www.mdpi.com/2071-1050/17/7/3002
[101] https://www.mdpi.com/2071-1050/17/7/3002
[102] https://www.mdpi.com/2071-1050/17/7/3002
[103] https://www.mdpi.com/2071-1050/17/7/3002
[104] https://cordis.europa.eu/project/id/314678/reporting
[105] https://cordis.europa.eu/project/id/314678/reporting

that added insulation does not cause overheating or poor ventilation. Using these standards helps policymakers and professionals to evaluate retrofit options in a consistent, heritage-aware manner, ensuring interventions are technically compatible, legally compliant, and sensitive to both people and place[106].

[106] https://www.iea-shc.org/Data/Sites/1/publications/D.B3--Handbook.pdf

F. LESSONS FROM THE ZEB4ZEN PILOT NEIGHBOURHOODS

This chapter shows how the strategy was derived from the concrete work carried out in the four ZEB4ZEN pilot neighbourhoods. The general regulatory overview and the technical measures (subsequent chapters) were confronted with the results of the technical and heritage assessments and with the preparation, implementation and evaluation of the pilot investments carried out within the project tasks. To avoid ambiguity, each statement is labelled as IMPLEMENTED (completed and verified within the project), IN OPERATION / MONITORING (implemented, results still being collected) or PLANNED / PROPOSED (recommended or foreseen, not yet implemented).

4. How the strategy was developed – tasks and inputs

In accordance with the tasks implemented in the project, the strategy builds on the following work, whose results were used as direct inputs:

Project task	Content used for the strategy	Where reflected in the strategy
Identification of neighbourhood energy supply and demand	Energy baselines of buildings, public lighting and transport in the four pilot neighbourhoods	Step 0 – neighbourhood definition and energy baseline
Joint methodology on energy data flows	Library of Buildings, typology-based "ambassador building" approach, KPIs, Sankey energy flows	Neighbourhood inventory and baseline; replication steps (this chapter)
Scanning and digital twins of the pilot neighbourhoods	3D scans / digital twins of the pilot areas, transnational digital-twin protocol	Documentation requirements; digital documentation
Assessment of the cultural heritage locations in the pilot neighbourhoods	Protection regimes, protected elements, permissible depth of intervention	Heritage baseline at neighbourhood scale; heritage constraints
Energy flows of cultural heritage sites	Energy flows of heritage buildings, public lighting and transport (Zamość, Zvijezda, Palmanova, Quedlinburg)	Prioritisation of measures; recapitulation of measures
Preparation, implementation and evaluation of the pilot actions	Lessons from the Zamość, Karlovac and Palmanova pilot investments	Sections on pilot lessons and common recommendations (this chapter)
Exchange of experience, transnational handbook and common methodology for monitoring and verification of savings	Common challenges, transferability, harmonised measurement of savings	Common recommendations; monitoring requirements

5. Main challenges identified in the four pilot neighbourhoods

Pilot neighbourhood	Heritage status	Main challenges identified
Zamość (PL) – Old Town	UNESCO World Heritage Site; Monument of History; buildings in the register of monuments	Façades cannot be insulated externally; thick historic masonry with poor thermal performance; thermal bridges and condensation risk at junctions; need for conservator approval of every intervention; repeated public tenders.
Karlovac (HR) – Zvijezda	Protected cultural-historical urban ensemble (Renaissance star fortress)	Restrictions on visible roof surfaces for PV (special conservation conditions); lack of space for stationary storage; immature market for V2G vehicles; repeated procurement procedures; large stock of unused and deteriorated buildings.
Palmanova (IT) – fortress town	UNESCO World Heritage Site (Venetian Works of Defence)	PV not permitted inside the city walls; limited awareness of energy communities; complex REC legal and incentive framework; need to engage many members (households, SMEs, public bodies).
Quedlinburg (DE) – Old Town	UNESCO World Heritage Site; protected under state monument law (Saxony-Anhalt)	Fragmented and incomplete energy data across administration and utility; many buildings in poor condition; strong monument protection limiting depth of renovation; need for planning tools rather than single-building measures.

6. Influence of the technical and heritage assessments on the strategy

The assessments carried out within the project tasks changed the strategy in four concrete ways:

- **Neighbourhood instead of building scale:** The energy-flow analyses showed that buildings, public lighting and transport must be assessed together (in Quedlinburg, for example, buildings account for the largest share of the neighbourhood's energy use, while lighting and transport also contribute noticeably). This is why Step 0 – neighbourhood definition and baseline – was introduced before any building-level procedure.
- **Heritage valorisation defines the permissible depth of renovation:** The heritage assessment and the Quedlinburg methodology integrated the protection level of each building into the inventory. The strategy therefore requires a heritage baseline at neighbourhood scale and a differentiation of measures by protection level.
- **Moisture and building-physics diagnostics first:** Thermography and in-situ U-value measurements in Zamość revealed thermal bridges and surface temperatures below the dew point. This confirmed the sequence “diagnosis → moisture control → envelope → services → renewables” .
- **Renewables outside or out of sight:** In Karlovac and Palmanova the heritage constraints made standard rooftop PV impossible or limited. The strategy therefore treats off-site generation, energy sharing and flexible (mobile) storage as neighbourhood-level options rather than exceptions.

7. Lessons from the Zamość thermal renovation pilot

IMPLEMENTED: Thermal modernisation of the usable attic and external partitions of the public utility building at Ormiańska 11 (part of a protected frontage of tenement houses), together with modernisation of selected building services (heating, ventilation and electrical installations). The works were designed and carried out in agreement with the conservation requirements. Vapour-permeable internal insulation systems (mineral insulation boards, sheep wool) were applied; original windows in good condition were retained.

RESULTS: The analyses indicate a substantial reduction of the energy demand for heating and ventilation and a lower heat load of the building. Post-retrofit measurements carried out by the Lublin University of Technology (thermography and in-situ heat-flow measurements) confirmed a clear improvement of the thermal performance of all investigated partitions – most pronounced for the external walls, and smaller for the attic slopes and ceiling – the elimination of condensation risk on internal surfaces and a more homogeneous surface-temperature distribution. In the preparation phase a research and monitoring station was installed in the Zamoyski Palace.

Lessons for the strategy:

- Capillary-active / vapour-open internal insulation is a workable solution where façades must remain untouched, provided it is designed on the basis of hygrothermal analysis and verified by measurements.
- Reduced insulation thickness around retained historic windows leaves residual thermal bridges – a conscious heritage trade-off that must be documented and monitored.
- Before/after thermography and in-situ U-value measurements are an inexpensive and convincing verification method and should be part of every heritage retrofit (MRV).
- Public procurement in heritage buildings needs time reserves: the pilot required repeated tender procedures and a contract amendment for additional works discovered during construction.
- Finishing materials must remain vapour-permeable during operation; operational recommendations should be handed over to the building user.

8. Lessons from the Karlovac green and digital energy investment

IMPLEMENTED: At the City Hall of Karlovac (Zvijezda) an integrated system was installed, consisting of a small rooftop PV plant designed under special conservation conditions, a bidirectional charging station, an electric vehicle with vehicle-to-load (V2L) functionality used as mobile storage, and an energy management system (EMS) for real-time monitoring and control.

RESULTS (ex-post evaluation based on the common ZEB4ZEN MRV methodology): the PV system covers a meaningful part of the building's electricity demand and reduces grid purchases and operating costs; the replacement of a conventional vehicle by an electric one brings additional energy and emission savings. The pilot shows a positive trend in self-consumption and flexibility, which is expected to grow with further operating experience.

DEVIATION: The originally planned vehicle-to-grid (V2G) concept could not be implemented because no V2G-capable vehicles were available on the Croatian market; procurement had to be repeated and specifications redefined. V2L was adopted as the functional alternative. PLANNED / PROPOSED: upgrading to V2G when the market and grid-code framework allow it.

Lessons for the strategy:

- Electric vehicles can act as flexible storage where there is no space for stationary batteries in historic buildings.
- Technical specifications for innovative technologies must be checked against market readiness before tendering; functional (performance-based) specifications reduce the risk of failed tenders.
- Digital energy management (EMS) is a low-impact measure that increases self-consumption without physical intervention into the heritage fabric.
- Early dialogue with the conservation authority is needed for any visible installation (PV) on protected roofs.

9. Experience from establishing the renewable energy community in Palmanova

IMPLEMENTED: Two PV plants were designed, built and commissioned on a marginal, non-productive area (a former landfill) outside the fortified town, where PV is permitted. The plants supply a Renewable Energy Community (REC/CER) serving members whose consumption points are inside the UNESCO-protected walls; the REC brings together households, SMEs and public bodies, including the Municipality of Palmanova.

IN OPERATION / MONITORING: The consumption of the public members alone is higher than the expected production of the plants, so a high level of virtual sharing can be expected. Measured shared energy and CO_2 savings over a full year are still being collected under the M&V plan.

Lessons for the strategy:

- Decoupling generation (outside the historic fabric) from consumption (inside the protected area) through virtual energy sharing is a replicable model for historic centres where rooftop PV is not acceptable.
- Brownfield or marginal municipal land is a valuable resource for neighbourhood-level renewables.
- The REC is as much a governance model as a technical one: information campaigns, trust-building and a clear statute are preconditions; anchor members with high daytime consumption (public bodies) secure the business case.
- For RECs the indicator is not ‘savings’ but produced and shared renewable energy – monitoring must be designed accordingly.

10. Results from Quedlinburg relevant to heritage-sensitive energy planning

IMPLEMENTED (analytical pilot): Quedlinburg did not carry out a physical investment pilot; its pilot action delivered a verified neighbourhood energy baseline and digital twin. A Library of Buildings was created for the pilot area, covering a mix of residential and non-residential buildings. The analysis shows that buildings – mainly heating – dominate energy use and emissions, while public lighting and transport play a smaller but relevant role. Data were provided by the City of Quedlinburg (monument preservation plan, building data, lighting) and the municipal utility (electricity, gas and local heating consumption over several years), complemented by surveys and audits of ambassador buildings.

Lessons for the strategy:

- Typology-based extrapolation from audited ‘ambassador buildings’ makes neighbourhood planning feasible even with incomplete data – a key element of Step 0.

- Integrating heritage valorisation into the building database allows the permissible depth of renovation to be defined per building before measures are optimised.
- Ownership of data by the municipality (energy atlas, digital twin) and regular updates from the local utility are necessary for long-term use in monument preservation and spatial planning.
- PLANNED / PROPOSED: use of the baseline and the EE/RES simulation tool to prioritise renovation measures in the Quedlinburg action plan.

11. Overview: implemented results versus planned or proposed actions

Pilot	Implemented / verified	In operation – results pending	Planned / proposed
Zamość	Internal insulation of attic and external partitions, modernised building services ; substantial reduction of heating demand; improved thermal performance confirmed by measurements	Long-term hygrothermal monitoring	Replication in other municipal heritage buildings of the Old Town
Karlovac	Rooftop PV, bidirectional charger, V2L electric vehicle, EMS at City Hall	Operational data for full year	Upgrade to V2G; extension to other public buildings in Zvijezda
Palmanova	PV plants built and commissioned outside the walls; REC with multiple members	Measured shared energy and CO_2 savings (M&V)	Enlargement of the REC; further members inside the walls
Quedlinburg	Library of Buildings, neighbourhood energy baseline, digital twin	-	Use in action plan and EE/RES optimisation; investment measures

12. Common recommendations derived from the pilot experiences

- **Plan at neighbourhood scale.** Start every retrofit programme with a neighbourhood baseline combining energy data and heritage valorisation (Quedlinburg and all pilot neighbourhoods).
- **Involve the conservation authority from the concept phase.** All pilots required conservation approvals; early joint site visits reduce redesign and delays (Zamość, Karlovac).
- **Diagnose before you insulate.** Use thermography, in-situ U-value and moisture measurements before and after works (Zamość).
- **Move generation where it is acceptable.** Combine off-site or less visible renewables with energy sharing or flexible storage (Palmanova, Karlovac).
- **Use digital tools for monitoring and management.** EMS, digital twins and harmonised MRV make results comparable and convincing (all pilots).
- **Design procurement for innovation.** Check market readiness, use functional specifications and plan time reserves for repeated tenders (Karlovac, Zamość).
- **Build governance and community.** Energy communities and citizen involvement need time, information and anchor members (Palmanova).

- **Plan realistic timeframes.** Heritage contexts require longer preparation and approval phases than conventional renovation (all pilots).

13. Differences between national regulatory frameworks and their implications for implementation

Country	Key framework	Heritage approval	Implications for implementation
Croatia	Building Act, energy and technical regulations; NECP update and National Building Renovation Plan; dedicated national programme for the energy renovation of cultural heritage buildings	Special conservation conditions and prior approval of the Ministry of Culture conservation department	Dedicated funding and guidelines exist; conservation conditions must be obtained before design of visible installations (Karlovac PV).
Italy	National legislation on energy performance, renewables and energy efficiency; Cultural Heritage Code; national REC framework	Authorisation of the Soprintendenza (Ministry of Culture), case-by-case	RES often excluded inside protected centres; the REC framework allows generation outside the historic fabric with virtual sharing (Palmanova).
Germany	Building Energy Act (GEG) with flexibility for monuments; state monument protection laws; federal funding programmes	Lower monument protection authority of the state (Denkmalschutzbehörde)	Decentralised, state-specific procedures; strong funding tradition (Städtebauförderung) supports planning-based approaches and data-driven prioritisation (Quedlinburg).
Poland	Act on the Energy Performance of Buildings; Act on the protection and care of monuments	Voivodeship Conservator of Monuments – permit for works on registered monuments	Exemption of monuments from energy-performance requirements; internal, reversible solutions and detailed documentation needed for conservator approval (Zamość).

Common implication: in all four countries energy requirements for monuments are relaxed, but there is no automatic obligation to improve them. Municipalities therefore need their own strategic commitment and local guidelines agreed with the conservation authority to move beyond case-by-case decisions.

14. Respecting UNESCO World Heritage requirements

Three of the four pilot neighbourhoods – Zamość, Palmanova and Quedlinburg – are inscribed on the UNESCO World Heritage List, and Zvijezda in Karlovac is a nationally protected urban ensemble. The pilot experience shows that in World Heritage contexts energy measures must be assessed not only against national monument law but also against the Outstanding Universal Value of the site and its management plan. The strategy therefore recommends:

- assessing visible or large-scale interventions (renewables, public-space works, new installations) for their impact on the attributes of the World Heritage property and its buffer zone, following the heritage impact assessment approach promoted by UNESCO and ICOMOS;
- involving the World Heritage site manager and the competent conservation authority from the concept phase, as was done in the pilots in cooperation with the conservation services;

- favouring internal, reversible and invisible measures inside the protected core and locating renewable generation in less sensitive areas, connected through energy sharing (as in Palmanova);
- integrating energy objectives into World Heritage management plans and local monument preservation plans, so that individual decisions follow a common, agreed framework (as foreseen in Quedlinburg).

15. From heritage retrofit to zero-emission neighbourhoods

The pilots illustrate complementary building blocks of a zero-emission neighbourhood in a historic setting: reducing demand in protected buildings (Zamość), producing, storing and managing renewable electricity locally (Karlovac), sharing renewable energy across the neighbourhood (Palmanova) and planning the transition on the basis of reliable neighbourhood data (Quedlinburg). None of these measures alone makes a historic neighbourhood zero-emission; the strategy therefore recommends combining them in neighbourhood action plans, so that demand reduction, renewable supply, flexibility and digital management reinforce each other while the heritage values of the ensemble are preserved.

16. Practical steps for municipalities wishing to replicate the strategy

- **Step 1 – Define the neighbourhood:** delineate boundaries along protection zones and energy-system logic; nominate an inter-departmental team (energy, heritage, planning, procurement).
- **Step 2 – Build the baseline:** create a Library of Buildings with heritage valorisation; collect utility data; audit ambassador buildings per typology; quantify energy flows and CO_2.
- **Step 3 – Agree heritage rules early:** hold a joint workshop with the conservation authority to define permissible measures per protection level and acceptable locations for renewables.
- **Step 4 – Select and optimise measures:** apply the sequence diagnosis → moisture → envelope → services → renewables; use multi-criteria optimisation developed in the project and neighbourhood solutions (shared generation, REC, EMS).
- **Step 5 – Start with a public pilot:** choose a municipal building with high visibility; measure before and after.
- **Step 6 – Prepare procurement:** check market readiness; use functional specifications; plan time reserves.
- **Step 7 – Organise governance and financing:** combine national heritage-retrofit programmes, EU funds and community models (REC); involve citizens and local businesses.
- **Step 8 – Monitor, report and scale up:** apply the common monitoring and verification methodology developed in the project; publish results; integrate them into the local action plan and spatial/monument preservation plans.

17. Tasks performed and partner contributions

In accordance with the tasks implemented in the project, the strategy was prepared jointly by the ZEB4ZEN partnership, building on the experience of the UNESCO World Heritage towns in the partnership and on the results of the pilot investments. It was developed in cooperation with the conservation services of the partner countries, so that the recommendations are applicable across different national contexts. The table summarises the role of each partner.

Partner	Country	Role and contribution to the strategy
Lublin University of Technology (PL)	PL	Contribution to the strategy and to the guidelines for improving the thermal efficiency of historic buildings; research, measurements and verification for the Zamość pilot; technical chapters on moisture rehabilitation, envelope and building services
City of Zamość (ZAMOSC)	PL	Pilot neighbourhood and pilot investment (thermal modernisation of a protected building); cooperation with the local conservation services; UNESCO World Heritage experience
Energy Institute Hrvoje Požar (EIHP) – Lead Partner	HR	Project coordination; methodology for neighbourhood energy flows and for monitoring and verification of savings; Croatian regulatory framework; support to the Karlovac pilot
City of Karlovac	HR	Pilot neighbourhood Zvijezda and green and digital pilot investment (PV, electric mobility, bidirectional charging, energy management); data for heritage assessment and energy flows
Energy Management Agency of Friuli Venezia Giulia (APE FVG)	IT	Coordination of the pilot investments; technical partner for Palmanova; renewable energy community model; Italian regulatory framework; NEB expertise
City of Palmanova	IT	Pilot neighbourhood and pilot investment (renewable energy community); UNESCO World Heritage experience
Magdeburg-Stendal University of Applied Sciences (HSMD)	DE	Technical partner for Quedlinburg; neighbourhood energy-flow analysis and digital tools; German regulatory framework
World Heritage Town of Quedlinburg (associated partner)	DE	Pilot neighbourhood without investment; data, monument preservation plan and UNESCO World Heritage experience
Associated heritage institutions (Soprintendenza Archeologia, belle arti e paesaggio del Friuli Venezia Giulia; Polish National Committee of ICOMOS)	IT / PL	Heritage protection perspective and support in aligning the recommendations with conservation principles

18. Adoption and application of the strategy

The strategy is intended to be formally endorsed by the pilot neighbourhoods – Karlovac, Palmanova, Zamość and Quedlinburg – through a letter of intent, confirming their commitment to apply its principles to energy-efficiency and renewable-energy investments in their protected areas. Because it is based on four different national contexts and neighbourhood types, the strategy is also designed to be applicable to a broader range of historic neighbourhoods in Central Europe, in particular through the practical replication steps described above.

G.CONCLUSION

The strategy on energy retrofit of cultural heritage neighbourhoods demonstrates that energy efficiency and conservation values are not contradictory but mutually reinforcing when managed through systematic, interdisciplinary planning. Beginning with moisture diagnostics and structural stabilization, followed by envelope insulation, system upgrades, and renewable integration, the pathway outlined respects the uniqueness of historic buildings while aligning with European climate targets.

The European legislative framework, notably the Energy Performance of Buildings Directive (EPBD) and the European Green Deal, provides an overarching mandate for decarbonisation, while EN 16883:2017 offers the methodological foundation for evaluating measures in heritage contexts[107]. The coordinated application of these instruments ensures that interventions are technically compatible, culturally respectful, and environmentally effective.

Case studies from Central Europe and beyond confirm that combinations of envelope measures, efficient HVAC and DHW systems, and on-site renewables can substantially reduce primary energy consumption in protected heritage buildings[108]. Importantly, these savings are achieved without undermining authenticity when reversible, vapor-permeable, and non-invasive solutions are prioritised.

Interdisciplinary collaboration remains the cornerstone of successful projects. Architects, engineers, conservators, material scientists, and policymakers must work jointly, supported by digital tools such as BIM and HiBERatlas repositories, to document, design, and monitor interventions. Lessons from INTERREG projects such as VIOLET, and EE-Heritage underline the need for knowledge transfer, capacity building, and cross-border cooperation in addressing the complex challenges of heritage retrofit[109].

Ultimately, the document advocates a pragmatic but ambitious roadmap: historic districts can become low-carbon and climate-resilient while preserving their cultural identity. By embedding energy retrofits into conservation practice, Europe can safeguard its heritage not only as a cultural asset but also as a model of sustainable urban transformation.

In this sense, the strategy is not a manual for retrofitting individual heritage buildings, but a framework for transforming historic neighbourhoods into low-carbon, climate-resilient urban systems, in which buildings, public space, infrastructure and governance are treated as one integrated heritage-energy ecosystem.

The experience of the four ZEB4ZEN pilots confirms this approach in practice: the Zamość pilot proved that internal, vapour-open insulation can significantly reduce heating demand in a protected building; Karlovac showed that PV, electric mobility and digital energy management can be combined under heritage constraints; Palmanova demonstrated that a renewable energy community can supply a UNESCO town from outside its walls; and Quedlinburg showed how a neighbourhood energy baseline and digital twin make heritage-sensitive planning possible even with incomplete data.

---

[107] Leijonhufvud G., Broström T., Eriksson P., Troi A., *Planning Energy Retrofits of Historic Buildings: EN 16883:2017 in Practice*, IEA SHC Task 59 | EBC Annex 76, 2021, available at: https://www.iea-shc.org/Data/Sites/1/publications/D.B3--Handbook.pdf

[108] Thravalou S., Michopoulos A., Alexandrou K., Artopoulos G., *Energy retrofit strategies of built heritage: using Building Information Modelling tools for streamlined energy and economic analysis*, IOP Conf. Ser.: Earth Environ. Sci., 1196, 012115, 2023, doi:10.1088/1755-1315/1196/1/012115

[109] de Santoli L., Garcia D.A., Groppi D., Belloni E., Palumbo M., Toschi L., *Integration of renewable technologies in historical and heritage buildings: A review*, Energy and Buildings, 177, 96–111, 2018, doi:10.1016/j.enbuild.2018.07.058