European Commission

Clean energy for EU islands: Energy efficiency in residential stone buildings

Clean energy for EU islands

Energy efficiency in residential stone buildings, especially in cold and damp climates

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List of Abbreviations

ACAs	Architectural Conservation Areas
DIT	Dublin Institute of Technology
EED	Energy Efficiency Directive
EPS	Expanded Polystyrene
EPBD	Energy Performance of Buildings Directive
ERV	Energy Recovery Ventilation
EU	European Union
HRV	Heat Recovery Ventilation
MEPS	Minimum Energy Performance Standards
NECP	National Energy and Climate Plan
NEEAP	National Energy Efficiency Action Plan
NSAI	National Standards Authority of Ireland
NZEB	Nearly Zero-Energy Buildings
RED	Renewable Energy Directive
SEAI	Sustainable Energy Authority of Ireland

Executive Summary

In the face of climate change, energy efficiency is undeniably crucial, requiring urgent action to reduce greenhouse gas emissions, lower energy consumption, and minimise associated costs. Enhancing energy efficiency is a vital strategy for mitigating climate impacts and advancing sustainable development.

This report examines energy efficiency measures for traditional buildings in Ireland, with a particular focus on the Aran Islands, which boast a rich portfolio of historic stone buildings. It highlights the European Union's (EU) regulations and directives aimed at improving energy efficiency and reducing carbon emissions, as well as Ireland's national policy framework.

Key retrofitting measures discussed in the report aim to improve thermal performance while preserving the external appearance of buildings in compliance with conservation regulations. These include solutions such as thermal renders, insulating panels, cladding systems, double- or triple-glazed windows, and heat recovery ventilation systems.

The report emphasises the importance of a holistic approach to retrofitting, prioritising measures that maximise energy savings without compromising the integrity and character of traditional buildings. It concludes that successful implementation of energy-efficient retrofits requires supportive policies, financial incentives, and well-structured programs that support various energy efficiency measures and provide capability-building initiatives.

1. Introduction

This study provides an analysis of the energy efficiency of traditional stone residential buildings, particularly in cold and damp climates, such as those found on the Aran Islands. Such buildings offer significant energy savings potential, indicating that substantial reductions in energy consumption can be achieved in traditional stone buildings when retrofitted with modern, energy-efficient technologies. Implementing both external and internal insulation strategies can **decrease energy use by up to 50%.**

The effectiveness of improving thermal performance through various retrofitting solutions, such as thermal renders, insulating panels, and cladding systems, was evaluated based on references provided in the References section below. Among these solutions, insulating panels and thermal renders were identified as particularly effective in significantly reducing heat losses and providing better occupant thermal comfort in cold weather conditions. However, effectively managing moisture to prevent damage to the stone structure while enhancing energy efficiency remains a critical challenge. One of the key aspects of the study is the importance of using **moisture-permeable materials** like lime-based renders that allow buildings to breathe while being thermally insulated.

Additionally, the study examines the benefits of integrating renewable energy systems, such as **biomass boilers and solar thermal panels**, to complement energy efficiency improvements. This integration not only reduces reliance on fossil fuels but also aligns with EU directives on increasing the share of renewable energy in building heating systems. The report outlines successfully demonstrated retrofitting projects such as the retrofit of a Georgian townhouse in Dublin and a traditional house in County Cork. These projects showcase the practical application of the recommended solutions to achieve significant energy savings while preserving the historical integrity of buildings.

2. Regulation

In the context of addressing climate change and promoting sustainable development, the European Union (EU) has established a set of regulations and directives to improve energy efficiency and reduce carbon emissions across its Member States. These regulations and directives are mostly interesting for countries with cold climates, where energy consumption for heating is a significant concern and can lead to overuse and misuse of energy. Ireland, which has a temperate maritime climate with cool winters, has transposed these EU directives into its national policy framework.

This integration ensures that both new and existing buildings are optimised for energy efficiency and resilience, aligning with the EU's stringent standards while respecting Ireland's unique climatic challenges. We outline herein these key EU regulations and directives related to energy efficiency in cold climates and how Ireland has implemented the regulations at the national level to enhance the energy performance of its building stock.

2.1. EU Regulations on Cold Climate

2.1.1. Energy Performance of Buildings Directive (EPBD)

One of the first EU regulations mentioned in the "*Deep Energy Renovation of Traditional Buildings*" guide by The Heritage Council of Ireland is the EPBD. This directive requires Member States to set minimum energy performance standards (MEPS) for buildings and ensure that all new buildings are close to nearly zero-energy buildings (NZEB) by a specific date. It also emphasises the need for energy performance certificates and regular heating and cooling system inspections.

The timelines for achieving NZEB for different building types in Ireland are as follows:

- Since November 2019: NZEB standard applies to all new dwellings.
- Since January 2021: NZEB standard applies to all new non-residential buildings and major renovations.

2.1.2. Renewable Energy Directive (RED)

This directive mandates the increased use of renewable energy sources in the EU energy mix, aiming for a significant share of renewable energy sources therein by 2030. It includes money allocated for integrating renewable energy in the heating and cooling sectors, which is crucial for cold climates. Ireland's Renewable Heat Incentive is a scheme designed to encourage the adoption of renewable heat technologies among businesses, households, and the public sector through financial incentives. The scheme provides financial incentives for businesses and homeowners to install renewable heating systems.

One example is the implementation of biomass boilers in rural schools, such as the installation at *Ballinteer Community School* in Dublin. The school replaced its old oil-fired heating system with a biomass boiler, thus reducing reliance on fossil fuels and utilising locally sourced wood pellets. This aligns with the emphasis of the Renewable Energy Directive (RED) on increasing the share of renewable energy, ensuring the school remains warm and energy-efficient during cold weather. The switch to a biomass boiler has **reduced the school's heating costs by 40%** and significantly reduced its carbon footprint.

2.1.3. Energy Efficiency Directive (EED)

The EED sets binding measures to help the EU reach its energy efficiency targets. These include requirements for renovations in buildings as well as efficient heating and cooling systems and energy savings obligations for utilities. Under the EED, Member States are required to implement measures that improve energy efficiency. Ireland's Better Energy Homes Scheme offers grants for homeowners to upgrade their insulation, heating systems, and controls.

An example is the retrofit of a traditional house in County Cork, whereby grants were used to improve roof and wall insulation by installing a high-efficiency gas boiler and adding a smart heating control system. The retrofit has resulted in a **30% reduction in energy consumption and heating bills** for the house.

2.1.4. Regulation on Energy Efficiency and Sustainability of Traditional Buildings

This regulation is focused on ensuring that renovations of traditional and historic buildings do not compromise their cultural and architectural value while enhancing their energy efficiency. This is directly related to buildings in cold climates where maintaining heat can be challenging due to traditional construction methods.

For stone house renovations, the regulation recommends using natural, breathable insulation materials like sheep wool or vapour-permeable boards to manage moisture effectively. For internal insulation, materials like insulating lime plaster are recommended to preserve the external appearance and prevent condensation within walls. Moreover, applying breathable render or mortar to the exterior to control moisture ingress allows walls to dry naturally.

Thermal performance draft-proofing can also be improved by installing energy-efficient windows and using high-efficiency heating systems. It is important to adopt a whole-house approach by considering the building as a system to ensure that energy upgrades do not compromise its historical character. Preserving original features such as stone façades and traditional windows while enhancing energy efficiency is crucial. To prevent future moisture problems, it is recommended to use hygrothermal modelling to assess moisture dynamics within walls. These steps help enhance energy efficiency while maintaining the historical integrity of stone houses.

2.1.5. EU Adaptation Strategy

This strategy provides a framework for building resilience against climate change impacts, including extreme cold weather events. It proposes that Member States develop national adaptation plans that include energy efficiency measures for buildings in cold climates.

2.2. Implementation of EU Regulations at the National Level in Ireland

2.2.1. National Energy Efficiency Action Plan (NEEAP)

Ireland's NEEAP incorporates EU directives that set out measures to improve energy efficiency across sectors, including building renovations and the promotion of renewable energy in heating and cooling. The plan specifically targets reducing energy use in buildings, which is critical for coping with cold climates and thereby becoming more efficient while maintaining occupant comfort.

Ireland's NEEAP was intended to achieve a **20% overall improvement in energy efficiency by 2020**, with **a 33% target precisely for the public sector**. The initiative was also aimed at

retrofitting 75,000 homes to achieve 20% energy savings in the residential sector, while the industrial and business sectors were expected to improve their energy efficiency by 20% through audits and the implementation of energy management systems.

Building regulations are aimed at achieving NZEB for new constructions by 2020, with a focus on retrofitting existing buildings. The plan encourages the increased use of renewable energy and promotes energy performance contracts to ensure ongoing energy savings and efficiency improvements.

2.2.2. National Energy and Climate Plan (NECP)

Ireland has released its NECP for 2021-2030 in July 2024. The milestone targets for 2030 in the residential sector include retrofitting the equivalent of **500,000 homes to a Building Energy Rating (BER) level of B2** or a cost-optimal equivalent or carbon equivalent.

2.2.3. Nearly Zero-Energy Buildings (NZEB) Standards

According to the EPBD, Ireland has set NZEB standards for new buildings and major renovations. The EPBD requires all new buildings to meet the NZEB standard by a specified date. Ireland implemented this by setting the target for all new public buildings to achieve NZEB status by the end of 2018 and all other new buildings by the end of 2020.

For example, the recently constructed Dublin Institute of Technology (DIT) Grangegorman campus incorporates high levels of insulation, triple-glazed windows, and an advanced mechanical ventilation system with heat recovery. The NZEB standard in Ireland requires that buildings have high energy performance and that the low amount of energy they require comes from renewable sources. The DIT Grangegorman campus comprises a combination of **solar thermal panels and a biomass boiler** to meet its heating needs, thus ensuring sustainability even in the winter.

2.2.4. Building Regulations and Technical Guidance Documents

These regulations incorporate EU standards and provide detailed guidance on implementing energy-efficient measures that consider Ireland’s cold and wet climate. They include specifications for insulation, ventilation, and the use of renewable energy sources.

2.2.5. National Adaptation Framework

This framework outlines Ireland’s strategy for adapting to climate change, including measures to improve the energy performance of buildings to withstand colder temperatures. It supports the integration of renewable energy and energy-efficient technologies in building design and renovation.

For instance, the framework has guided the retrofitting of public housing in the west of Ireland, where the climate is particularly harsh. In Galway, public housing estates were upgraded with external wall insulation and the installation of energy-efficient windows and doors. Such retrofits ensure that homes maintain a consistent and comfortable indoor temperature during the winter, thus reducing the risk of heat loss and improving overall energy efficiency. Residents now enjoy lower energy bills and increased comfort during colder periods.

2.2.6. Support and Funding for Energy Renovation

The Sustainable Energy Authority of Ireland (SEAI) provides grants and funding for energy efficiency improvements in buildings. These initiatives are aligned with EU directives and are focused on enhancing the energy performance of buildings, including those in cold climates, to reduce energy consumption and greenhouse gas emissions.

Alongside such measures, the SEAI has distributed home energy-saving kits through public libraries to raise awareness and educate the public about energy efficiency. These kits include tools to measure heat loss, assess insulation, and identify areas for improvement in homes. The SEAI also provides training for construction professionals on best practices for energy-efficient retrofits, emphasising techniques suited to Ireland's cold climate.

An example is the **Deep Retrofit Pilot Programme**, which serves to train professionals in comprehensively managing energy efficiency projects.

2.2.7. National Standards Authority of Ireland (NSAI) Recommendations

NSAI has developed recommendations for the energy-efficient renovation of traditional buildings. These recommendations consider the unique characteristics of traditional Irish buildings and the need for measures that are effective in a cold climate without compromising the building's historical values.

The focus of the EU on sustainable retrofitting has been applied in Dublin's Georgian Quarter. One example is the retrofit of a Georgian townhouse on Fitzwilliam Street. The retrofit included installing **secondary glazing on existing windows**, improving attic insulation, and upgrading the heating system to a high-efficiency gas boiler. Care was taken to preserve the building's historical features, including its original sash windows and plasterwork.

The project achieved a **50% reduction in heating costs** and significantly improved thermal comfort without compromising the building's architectural integrity. [1]

3. Traditional Irish Buildings

Traditional buildings in Ireland generally include those built with solid masonry walls made of brick, stone, or clay, using lime-based mortars often with a lime or earthen-based render finish, single-glazed timber or metal-framed windows, and a timber-framed roof usually clad with slate but often with tiles, copper, lead or, less commonly, corrugated iron or thatch. In general, these were the dominant forms of building construction from medieval times until the second quarter of the twentieth century.

The primary difference between traditional and modern construction is in the way moisture is managed in external walls. Traditional materials and construction techniques allow for the natural transfer of heat and moisture. Solid masonry walls, therefore, relied on their thickness to cope with atmospheric moisture, the walls being sufficiently thick to ensure that drying out took place before external moisture reached the inner face of the wall. External lime renders were sometimes used as a weathering coat to reduce the amount of moisture absorbed by walls without trapping interstitial moisture, i.e. moisture occurring within the thickness of the wall.

Many traditional buildings in Ireland were built in this manner, and it is therefore essential that all materials and finishes, including mortars, renders and plasters, used on traditional walls are vapour-permeable materials that both absorb and readily allow the evaporation of moisture.

Stylistically, traditional Irish buildings vary widely and include vernacular or architect-designed residential, industrial, commercial, and institutional buildings. Ireland also has a rich legacy of solid-walled medieval structures, many of which remain in use as habitable buildings. It should be noted that while some traditional buildings are protected structures or are located within architectural conservation areas (ACAs), the majority are not. Care must still be taken with non-protected traditional buildings as energy-efficiency upgrades can adversely affect the character or fabric of such buildings if incorrectly implemented.

3.1. Responsible Sustainable Retrofit

Traditional buildings often embody significant historical, cultural, and architectural values. It is, therefore, important to approach retrofit projects with a sense of responsibility that balances the need for modern energy efficiency with the preservation of those attributes.

3.2. Understanding Responsible Retrofit

Responsible retrofitting refers to the process of improving the energy performance of traditional buildings in a way that minimises negative impacts on their fabric, character, and the health of their occupants. The goal is to achieve a holistic and sustainable upgrade that respects the building's historical and architectural significance while meeting contemporary energy standards.

3.3. Key Principles of Responsible Retrofit

1. **Whole Building Approach**: Responsible retrofit requires an integrated strategy that considers the building's fabric, services, and the behaviour of its occupants in a unified way. This involves examining how elements like insulation, heating systems, and ventilation work together to maintain or enhance overall building performance.
2. **Energy and Environmental Impact:** Effective retrofitting should lead to real reductions in energy use, thereby lowering operational costs and carbon emissions. This is typically

achieved through measures such as improving insulation, upgrading heating systems, and incorporating renewable energy sources. Additionally, minimising the embodied impact of materials and the construction process is vital for environmental sustainability.

3. **Health and Well-Being**: A significant aspect of responsible retrofitting is improving the health and comfort of building occupants. To prevent health problems and ensure a comfortable living environment, issues like moisture management, air quality, and temperature regulation must be considered. This involves enabling occupants to manage and maintain these systems easily.
4. **Heritage Protection:** Traditional buildings are often integral to the character of a community and hold substantial historical value. A responsible retrofit should maintain those qualities. This includes careful consideration of alterations to ensure they do not damage the building's fabric or detract from its historical significance.
5. **Context-Specific Solutions**: The retrofit approach must be tailored to the specific conditions of the given building, such as construction type, historical significance, and environmental exposure. Standardised solutions are often inadequate for traditional buildings because they require customised strategies that respect their individual characteristics and contexts.

3.4. Challenges and Risks

Missteps in the retrofit process, such as applying inappropriate standards or failing to adopt a correct approach, can lead to undesired consequences such as increased energy use, damage to the building fabric, or adverse health effects for occupants.

3.5. Practical Steps for Responsible Retrofit

1. **Assessment**: Conduct thorough evaluations of building conditions, historical significance, and current energy performance. This includes an analysis of potential risks related to moisture, thermal performance, and structural integrity.
2. **Design and Planning**: Develop a retrofit plan that integrates energy efficiency improvements with the building's heritage and health requirements. This plan should prioritise interventions that offer the best balance between energy savings, costs, and the preservation of historical values.
3. **Implementation**: Ensuring high-quality workmanship is crucial for maintaining building integrity and achieving the desired energy performance while respecting the original design.
4. **Monitoring and Maintenance**: After the retrofit, continued monitoring is required along with checking on regular maintenance to ensure that interventions perform as intended over the long term. Feedback from occupants can help identify areas for further improvement and ensure ongoing benefits.

A responsible, sustainable retrofit is not just about reducing energy consumption; it is also about ensuring that traditional buildings continue to serve as valuable cultural and historical assets while meeting the demands of contemporary living. [2]

3.6. External Insulation

Externally insulating stone walls require careful consideration to ensure both energy efficiency and the preservation of the building's structural integrity and aesthetics. Best practices include first assessing the stone wall for any structural issues or moisture problems and addressing these before installing insulation. Vapour-permeable, breathable insulation materials, such as mineral wool or wood fibre, are recommended to allow the wall to breathe and prevent moisture buildup. The insulation should be covered with a weather-resistant, breathable membrane to protect against rain while allowing moisture vapour to escape. Installing a supportive framework, such as a timber battens system, helps create a cavity for the insulation and facilitates secure attachment. Finally, the outermost layer, typically render or cladding, should be chosen to complement the building's aesthetic while providing additional protection against the elements. These steps ensure that the stone wall retains its thermal mass properties and aesthetic appeal while significantly improving its thermal performance. [3]

3.7. Thermal Renders

MATERIALS:	**Lime-based renders with glass beads or wood fibres**
THERMAL CONDUCTIVITY:	**0.05-0.10 W/mK**
U-VALUE IMPROVEMENT:	**From 2.5 W/m²K to 0.6-0.8 W/m²K**
COST:	**€60-€120/m²**

Thermal render involves adding an insulation layer directly to the exterior walls of a building and then covering it with a protective and decorative render. This insulation layer typically consists of materials like expanded polystyrene (EPS), mineral wool, or polyurethane. Once insulation is applied to the walls, a multi-layered render system is applied. This system usually includes a base coat with reinforcement mesh to provide stability and prevent cracks, as well as a finishing coat that is both weather-resistant and decorative. The primary advantage of this approach is its ability to significantly reduce heat loss, thereby improving building thermal efficiency and lowering energy costs. Additionally, it provides protection against weather elements such as rain, wind, and UV radiation. [4]

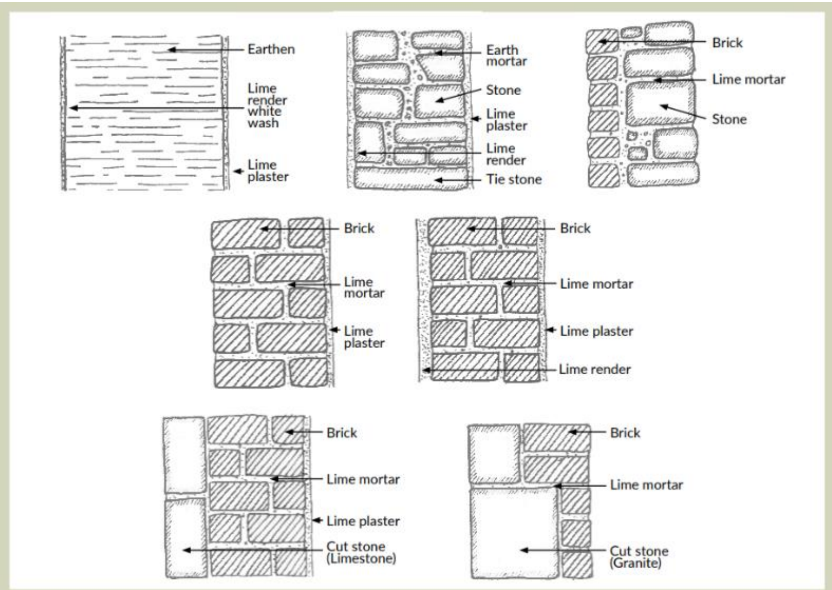

Figure 1: Illustrative examples of different types of traditional masonry walls and their typical buildup, source: "Energy Efficiency in Traditional Buildings"

Figure 2: The same building with fixed drainpipe leak and cement render replaced with a traditional moisture-permeable lime render, source: "Energy Efficiency in Traditional Buildings"

3.8. Insulating Panels

MATERIALS:	**Wood fibre, hemp, or flax panels**
THERMAL CONDUCTIVITY:	**0.04-0.05 W/MK**
U-VALUE IMPROVEMENT:	**0.3-0.4 W/M²K**
COST:	**€40-€80/M²**

Insulating panels are an effective method for enhancing the thermal performance of buildings. These panels are pre-manufactured from materials like rigid foam, expanded polystyrene, or phenolic boards. The panels are attached to the exterior walls of the building to provide a continuous layer of insulation. This method is known for its installation ease and speed as the panels are fixed to the wall and then covered with a protective and decorative finish such as a render or cladding. Insulating panels provide high thermal resistance, making them particularly effective at preventing heat loss and maintaining stable indoor temperatures. [4]

3.9. Cladding Systems

MATERIALS:	**XPS or PUR panels under timber/composite cladding.**
THERMAL CONDUCTIVITY:	**XPS ~0.03 W/mK, PUR ~0.02 W/mK**
U-VALUE IMPROVEMENT:	**0.2-0.3 W/m²K**
COST:	**€70-€150/m²**

Cladding systems involve covering the exterior of a building with a layer of material that serves both aesthetic and functional purposes. The cladding is installed over an insulation layer, which provides thermal protection. The materials used for cladding can vary widely and include options such as wood, metal, vinyl, fibre cement, or composite materials. These materials are attached to a framework mounted onto the building's exterior walls to create a cavity between the wall and the cladding. The cavity not only improves insulation but also facilitates ventilation, helping to prevent moisture buildup and prolong the life of the building structure. Cladding systems help improve energy efficiency, enhance weather resistance, and provide a modern appearance. They also offer an additional layer of protection against external elements, such as wind and rain, to help maintain the building's structural integrity over time. [5]

4. Internal Insulation

Internally insulating stone walls require a careful balance to enhance energy efficiency while maintaining the building's structural health and historical value. Best practices begin with addressing any existing moisture or structural issues in the walls to prevent future damage. A vapour-permeable insulation material, such as mineral wool or wood fibre, is recommended to allow the wall to breathe and manage moisture. A vapour control layer should be placed on the warm side of the insulation to prevent moisture from penetrating the wall. Creating a gap between the insulation and the stone wall also helps manage moisture and allows for any necessary air circulation. Installing a stud wall or battens to hold the insulation in place provides additional stability. It is essential to ensure that all joints and gaps are well-sealed to prevent thermal bridging and air leakage. Finally, finishing the interior with a breathable plaster or drywall helps maintain the wall's ability to manage moisture while providing a clean, finished appearance. These practices ensure that internal insulation enhances thermal performance without compromising the integrity or appearance of the stone walls.

4.1. Insulating Plasters

MATERIALS:	**Lime plasters with cork or perlite**
THERMAL CONDUCTIVITY:	**0.05-0.07 W/mK**
U-VALUE IMPROVEMENT:	**From 2.5 W/m²K to 0.7-0.9 W/m²K**
COST:	**€30-€60/m²**

Insulating plasters are specialised plasters that incorporate materials such as expanded perlite, aerogel, or vermiculite, which possess excellent insulating properties. When applied to interior walls, these plasters not only offer a seamless finish but also significantly improve the thermal wall resistance. This means that heat is more effectively restricted within the building, thereby reducing the need for additional heating and lowering energy costs. Insulating plasters are particularly useful in older or heritage buildings whose external insulation may not be feasible or desirable due to aesthetic or structural reasons. [4]

Figure 3: Thermal image showing additional heat flow at vertical and horizontal junctions with the abutting walls and floor. Note that the corner is the coldest point because it loses heat in three dimensions

4.2. Insulating Panels

MATERIALS:	Calcium silicate or aerogel panels
THERMAL CONDUCTIVITY:	Calcium silicate ~0.03 W/mK, aerogel ~0.015 W/mK
THICKNESS:	20-30 mm
U-VALUE IMPROVEMENT:	0.3-0.4 W/m^2K
COST:	€80-€200/m^2

Insulating panels are pre-manufactured from high-performance insulating materials like foam insulation or mineral wool. They are designed to be fixed directly to the inside of exterior walls using adhesives or mechanical fasteners. Insulating panels provide substantial thermal insulation, helping to keep the interior warm by preventing heat from escaping through the walls. The installation process is quick and straightforward, making them a popular choice for retrofitting existing buildings. Additionally, these panels are used mostly in conjunction with a vapour barrier to help prevent moisture issues that could lead to mould and dampness within the building structure. [5]

4.3. Cavity Wall Insulation

MATERIALS:	EPS beads or phenolic foam
THERMAL CONDUCTIVITY:	EPS ~0.04 W/mK, phenolic foam ~0.02 W/mK
U-VALUE IMPROVEMENT:	0.4-0.5 W/m^2K
COST:	€25-€50/m^2

Cavity wall insulation consists of two layers of masonry with a gap (cavity) between them. It involves filling the gap with insulating material such as foam, beads, or mineral wool injected or blown into the cavity through small holes drilled in the exterior wall. This method is highly effective in reducing heat loss as the insulating material creates a barrier that prevents the movement of heat through the walls. Once installed, cavity wall insulation is invisible from both the inside and outside, thus maintaining the building's aesthetic while significantly enhancing its energy performance. This type of insulation is particularly common in buildings constructed after the 1920s. However, cavity wall insulation might not be the best option for old solid stone houses due to the irregularity of their cavities.[4]

5. Complementary Approaches

Complementary approaches to externally insulating stone walls include enhancing ventilation, maintaining the integrity of the walls, leveraging thermal mass, and installing high-performance windows. Ensuring proper ventilation is crucial to prevent moisture buildup and condensation within the wall structure, which can be achieved using ventilation gaps or breathable membranes. Regular maintenance of stone walls, including repointing and repairing cracks, helps preserve the integrity of the wall and prolongs the effectiveness of insulation. Leveraging the thermal mass of stone walls can stabilise indoor temperatures by absorbing heat during the day and releasing it at night, thereby reducing the need for additional heating and cooling. High-performance windows, such as double or triple-glazed units with low-emissivity (low-E) coatings, further enhance energy efficiency by minimising heat loss and reducing drafts, complementing the overall insulation strategy. These integrated measures work together to optimise the energy efficiency, durability, and comfort of stone wall buildings.

5.1. Ventilation

SYSTEM:	**MVHR systems**
COST:	**€2,000-€5,000**
ENERGY SAVINGS:	**Up to 20%**

Proper ventilation is crucial for maintaining indoor air quality and controlling humidity. Mechanical systems like heat recovery ventilators (HRVs) and energy recovery ventilators (ERVs) are effective. HRVs retain heat from outgoing air, while ERVs manage both heat and moisture, reducing the risk of dampness and mould.

5.2. Wall Maintenance

TECHNIQUES:	**Lime mortar repointing**
COST:	**€50-€100/m²**

Maintaining stone walls involves adding insulation and ensuring moisture control. Interior or exterior insulation helps reduce heat loss. Vapour barriers prevent indoor moisture from condensing within the walls. Regular inspections and proper drainage systems are essential to prevent moisture ingress and structural damage.

5.3. Thermal Mass

MATERIALS:	**Stone, solid bricks**
THERMAL CONDUCTIVITY:	**Stone ~2 W/mK, solid bricks ~0.7 W/mK**

The high thermal mass of stone helps in stabilising indoor temperatures by absorbing and releasing heat slowly. Passive solar heating maximises sunlight exposure to stone surfaces to reduce heating needs. Radiant heating systems provide steady, low-level heat that the stone can absorb and release gradually.

5.4. High-Performance Windows

MATERIALS:	**Double or triple-glazing**

U-VALUE:	**Double glazing ~1.1 W/m²K, triple glazing ~0.7 W/m²K**
COST:	**Double glazing ~€300-€600 per window, triple glazing ~€500-€1,000 per window**
ENERGY SAVINGS:	**Up to 30%**

Windows are a significant source of heat loss. Double or triple glazing, low-E coatings, and thermal breaks in frames help reduce such loss. Proper installation and the use of insulated window treatments can further enhance energy efficiency.

Figure 4: Examples of retrofitted traditional buildings, source: "Ballinahown, Co. Galway Deep Retrofit Case Study," Kore System. Available online: https://www.kore-system.com/case-studies/ballinahown-co-galway-deep-retrofit-case-study/. [Accessed: June

6. Case Studies

Some buildings have already been upgraded to be more energy-efficient. A document titled *Energy Efficiency and Historic Buildings: Insulating Solid Walls* presents four case studies that illustrate various approaches and considerations for improving energy efficiency in historic buildings with solid walls. [6]

6.1. Case Study: Early 20th Century Semi-Detached House

- **Location**: The house is situated in a conservation area.
- **Project**: Reduce home energy consumption and improve occupant comfort.
- **Approach**: Install internal insulation to avoid altering the building's external appearance, which is protected under conservation regulations.
- **Method**: Breathable wood-fibre board insulation was applied to the inner surface of the external walls.
- **Outcome**: The internal insulation improved thermal performance while maintaining the external aesthetics. Careful consideration of the building's moisture dynamics was essential to prevent issues such as condensation.

6.2. Case Study: Victorian Terrace House

- **Location**: This house is part of a historic terrace in an urban setting.
- **Project**: Retrofit the house to meet modern energy standards without compromising its historic character.
- **Approach**: Both internal and external wall insulation was installed on the house. The front façade, which faced the street, was insulated internally to maintain the building's historical appearance, while the less visible rear and side walls were externally insulated.
- **Method**: A combination of mineral wool for internal insulation and an external insulation system with a render finish.
- **Outcome**: The project successfully balanced the need for energy efficiency with the conservation of the building's historical features. This dual approach significantly reduced heat loss.

6.3. Case Study: Georgian Manor House

- **Location**: This large historic house is in a rural setting and is listed for its architectural significance.
- **Project**: Enhance the building's energy efficiency while preserving its historical integrity.
- **Approach**: The owners opted for internal insulation throughout the house to avoid altering the historic exterior.
- **Method**: Insulating plaster directly to the interior walls. The use of a breathable lime-based plaster to ensure moisture could still move through the walls to prevent the risk of dampness.
- **Outcome**: The use of insulating plaster provided a subtle yet effective means of enhancing the building's thermal performance, which was crucial for a property with stringent conservation requirements.

6.4. Case Study: Edwardian School Building

- **Location**: This educational building is part of a listed complex and is situated in a conservation area.
- **Project**: The goal was to upgrade the building’s energy performance while respecting its historical value.
- **Approach**: External wall insulation to the rear and side walls, which were not visible from the main public viewpoints, and internal insulation was used for the prominent front façade.
- **Method**: High-performance external insulation panels and lime render to match the original look of the building. Internally, insulating panels were used behind the plasterboard.
- **Outcome**: This approach enabled significant energy savings while preserving the building’s historic appearance, particularly on the more visible front façade. [5] [7]

7. Conclusions

The findings of this study underscore the substantial potential for enhancing the energy efficiency of traditional stone buildings in cold and damp climates. The research highlights that a comprehensive retrofit approach, incorporating both internal and external insulation, as well as other energy-efficiency measures such as the installation of high-performance windows (double and triple glazing) and heat recovery ventilation, along with renewable energy integration, can lead to substantial energy savings and improved thermal comfort for residents. This approach not only reduces energy costs but also contributes to the overall sustainability and resilience of such buildings.

Balancing the **enhancement of energy efficiency with the preservation of the historical** and architectural value of traditional stone buildings is crucial. The study advocates for the use of materials and techniques that respect building heritage while achieving modern energy standards.

The successful implementation of energy-efficient retrofits requires supportive policies, financial incentives, and programmes that include a diverse portfolio of energy efficiency measures, enabling beneficiaries to undertake major renovations and optimise their energy savings. These programmes should also provide capability-building training that emphasises the importance of energy efficiency measures and the cost-effectiveness of implementing them. The study highlights the importance of EU directives and national programmes that provide funding and guidance for energy renovation projects, which are crucial for driving the widespread adoption of such measures.

Future research and innovation are crucial for developing and refining retrofitting techniques that address the unique challenges of traditional stone buildings in cold climates. This includes exploring new materials and methods that can provide even better moisture management and thermal performance. In conclusion, the study **provides practical steps for improving the energy efficiency of traditional stone buildings**. The implementation of these findings will not only enhance the comfort and well-being of occupants but also help meet broader environmental and climate goals.

8. References

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9. Appendices

9.1. Types of Insulation and Their Thermal Properties

The following table provides a comprehensive overview of diverse types of insulation materials, their thermal conductivity, and their impact on U-values when applied to traditional stone buildings.

INSULATION TYPE	THERMAL CONDUCTIVITY (W/MK)	U-VALUE IMPROVEMENT (W/M²K)	COST (€/M²)
Lime-Based Renders	**0.05 - 0.10**	**2.5 → 0.6 - 0.8**	**60 - 120**
Wood Fiber Panels	**0.04 - 0.05**	**2.5 → 0.3 - 0.4**	**40 - 80**
XPS Panels	**~0.03**	**2.5 → 0.2 - 0.3**	**70 - 150**
Calcium Silicate	**~0.03**	**2.5 → 0.3 - 0.4**	**80 - 200**

Source: "Energy Efficiency in Traditional Buildings"

9.2. Comparison of Insulation Materials

The following table compares various insulation materials, including their thermal properties, environmental impact, and cost-effectiveness, to provide a useful reference for selecting appropriate materials for energy efficiency improvements.

MATERIAL	THERMAL CONDUCTIVITY (W/MK)	ENVIRONMENTAL IMPACT	COST (€/M²)
Lime Plasters	**0.05 - 0.07**	**Low**	**30 - 60**
Hemp Panels	**0.04 - 0.05**	**Medium**	**40 - 80**
Aerogel Panels	**~0.015**	**High**	**150 - 300**
Phenolic Foam	**~0.02**	**Medium**	**25 - 50**

Source: "Energy Efficiency in Traditional Buildings"

9.3. Insulation Performance and Cost Analysis

The following table outlines the results of a detailed analysis of the performance and costs associated with different insulation options for traditional stone buildings to help guide effective decision-making for energy efficiency retrofits.

INSULATION OPTION	THERMAL CONDUCTIVITY (W/MK)	U-VALUE (W/M²K)	COST (€/M²)
Thermal Renders	**0.05 - 0.10**	**0.6 - 0.8**	**60 - 120**
Insulating Panels	**0.03 - 0.05**	**0.3 - 0.4**	**40 - 200**
Cavity Wall Insulation	**0.02 - 0.04**	**0.4 - 0.5**	**25 - 50**

Source: "Traditional Buildings"

9.4. Cost Breakdown for Retrofitting Traditional Buildings

The following table breaks down the costs involved in retrofitting traditional buildings with various energy efficiency measures, thus offering a detailed financial perspective on different approaches.

RETROFITTING MEASURE	ESTIMATED COST (€/M²)	TOTAL COST (€)
External Insulation	**60 - 150**	**6,000 - 15,000**
Internal Insulation	**40 - 200**	**4,000 - 20,000**
High-Performance Windows	**300 - 1,000 per window**	**3,000 - 10,000**
Ventilation Systems	**2,000 - 5,000**	**2,000 - 5,000**

Source: “Traditional Buildings”