

Review

Balancing Efficiency and Conservation: A Review of Energy Retrofitting Approaches for Historical Buildings in the Mediterranean Context

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Abstract

Improving the energy performance of historical buildings is a key challenge for decarbonising the European built environment. In the Mediterranean context, retrofit design is especially complex because interventions must reduce heating and cooling demand while preserving architectural and cultural values. Although research on this topic has grown, available evidence remains fragmented, with studies often focused on individual case studies and isolated retrofit packages. This review systematises the literature on energy retrofit interventions for historical buildings in the European Mediterranean region by linking retrofit measures, energy outcomes and conservation constraints. A PRISMA-based workflow was used to select articles published between 2010 and 2025 from Scopus and Web of Science. The results show a predominance of envelope-based measures, often combined with HVAC improvements. Passive–active packages achieve the highest reported reductions, up to 87% for heating and 75% for cooling. Conservation constraints do not necessarily prevent energy improvement, but they influence the admissibility, location and invasiveness of retrofit measures. Overall, the evidence indicates that energy retrofit of Mediterranean historical buildings should focus on heating reduction, cooling resilience and hygrothermal safety. The review provides a framework for identifying compatible retrofit pathways according to the architectural and material transformability of historical buildings.

Keywords: historical building; mediterranean climate; energy retrofit; seasonal energy performance



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1. Introduction

Energy efficiency in the existing building stock is a central issue in the European transition towards a low-carbon built environment. Buildings account for approximately 40% of final energy consumption in the European Union and are responsible for a substantial share of greenhouse gas emissions [1]. Within this stock, historical buildings represent a particularly sensitive and strategic category. They constitute a significant portion of European cities and settlements, especially in Mediterranean countries, where the built heritage is not limited to monumental or listed assets but also includes ordinary residential and urban fabric with historical, cultural, architectural, and material value [2,3]. For this reason, historical buildings cannot be considered a marginal exception to decarbonisation policies:

their continued use, adaptation, and energy improvement are essential both for reducing energy demand and for preventing abandonment, degradation, and loss of heritage value.

A complex interaction between construction features, climate, use, and conservation requirements shapes the energy performance of historical buildings. Traditional Mediterranean buildings are commonly characterised by massive masonry walls, timber single-glazed windows, limited airtightness, and poorly insulated roofs or floors [4,5]. These characteristics often generate high heating demand and indoor discomfort during winter, even in climates generally perceived as mild. At the same time, their massive envelopes and traditional passive strategies can contribute to summer thermal stability by delaying and attenuating heat flows [6]. This dual behaviour is particularly relevant within the European region characterised by a Mediterranean climate (in Figure 1, the extension of the Mediterranean climate within Europe is reported), where buildings must respond to both winter heating needs and increasingly critical summer conditions, intensified by climate change, longer warm seasons, heatwaves, and growing cooling demand [7–10].

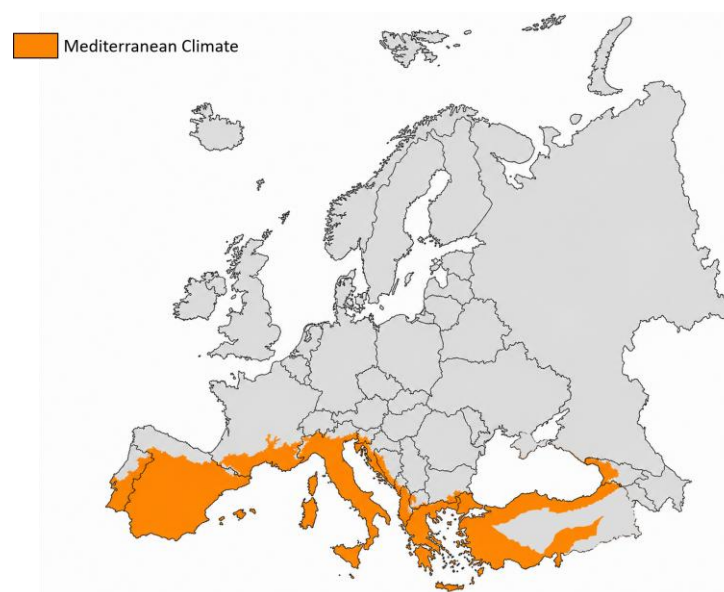


Figure 1. Extension of the Mediterranean climate in Europe, inspired by Ref. [11].

Energy retrofitting in this context is therefore not a simple process of applying standard efficiency measures. Interventions that are effective in ordinary buildings, such as external insulation, window replacement, photovoltaic integration, or intrusive heating, ventilation and air-conditioning (HVAC) systems, may be limited or excluded when they alter façades, interiors, construction materials, or the visual relationship between the building and its urban context [12,13]. External insulation may be substituted by internal insulation to preserve external appearance, but it could lead to summer overheating [14] or moisture failures such as interstitial condensation and mould growth [15]. As a matter of fact, adding an internal insulation layer to an existing wall reduces its drying capacity, leading to higher moisture levels on the inner face of the wall [16]. To reduce this risk, capillary-active insulation materials, e.g., calcium silicate board, are suggested due to their vapour permeability, as reported in the recent literature [17,18]. Similarly, renewable energy systems and mechanical equipment may offer substantial decarbonisation potential but are often constrained by visual, spatial, archaeological, or reversibility requirements. As a result, retrofit design for historical buildings requires a case-by-case balance between energy efficiency, indoor comfort, technical feasibility, and heritage conservation.

Several standards, protocols, and European research initiatives have contributed to framing this balance. EN 16883:2017 provides a decision-making methodology for

improving the energy performance of historic buildings while respecting their heritage significance [19]. In parallel, tools such as the GBC Historic Building protocol and European projects including EFFESUS, 3ENCULT, and CALECHE have supported the development of compatible retrofit approaches [20–23]. The recent literature has also expanded from individual technical measures to broader methodological frameworks, decision-support tools, sustainability assessment systems, and urban-scale approaches [24–26]. Other studies have focused on specific materials and technologies, including thermal plasters (TPs) [27–29], aerogel-based systems [28,30], bio-based materials [28–30], phase change materials (PCMs) [28–30], cool roofs and green roofs [28,30], heat pumps (HPs) [28,30], mechanical ventilation (MV) [30], and renewable energy integration [28–30].

Despite this growing body of research, the available evidence remains fragmented. Many studies are based on individual case studies and/or isolated retrofit measures, making it difficult to compare results across different retrofit interventions and conservation constraints. Against this background, this study aims to support the preliminary identification of compatible retrofit strategies for different levels of architectural and material transformability, through a systematic literature review on energy retrofit interventions applied to historical buildings in the European Mediterranean region. The novelty lies in connecting retrofit measures, energy outcomes, and heritage constraints, thereby identifying the most recurrent passive, active, and combined retrofit strategies and clarifying how different degrees of conservation constraint influence the selection of compatible interventions. By doing so, the study is guided by the following research questions:

1. Which passive, active, and combined retrofit measures are most frequently reported for historical buildings in Mediterranean Europe, and what ranges of reported heating- and cooling-energy impacts are associated with the main retrofit measures and packages?
2. How does the degree of constraint of historical buildings affect the selection of retrofit measures in Mediterranean Europe?

The structure of the paper is organised as follows. Section 2 explains the review methodology and the selection criteria. Section 3 presents the results, focusing on the main combinations of retrofit interventions for historical buildings in the European Mediterranean region. Section 4 discusses the evidence of the articles and the picture obtained from the classification. Section 5 concludes by answering the research questions and highlighting future research needs.

2. Materials and Methods

This study is based on a structured search conducted on Scopus and Web of Science to identify journal articles published between 2010 and 2025. Records were eligible if the title, abstract, or author keywords contained at least one term from each conceptual block listed in Table 1. Each block focuses on a specific theme: (i) the action (retrofit, renovation), (ii) the retrofit subject (energy), (iii) the object (historical buildings and common variants), and (iv) the geographical context (the Mediterranean/Southern Europe, country names and demonyms). Within each block, synonymous terms were combined with OR, while blocks were combined with AND. Multi-word expressions were enclosed in quotation marks, and truncation/wildcards (e.g., retrofit*, Ital*) were used to capture morphological variants.

The initial number of studies identified on Scopus and Web of Science is 157 and 176, respectively, of which 141 were present in both databases. The total number of papers analysed following the PRISMA workflow was 192. In the first stage (title/abstract screening), 102 records were excluded because they: (i) addressed non-residential building functions; (ii) focused exclusively on structural or other types of retrofit; (iii) were published in a language other than English; (iv) were outside the Mediterranean/Southern European context; or (v) were not accessible. In the second stage (rapid full-text appraisal of aims,

objectives and conclusions), 53 articles were excluded due to mismatched outcomes relative to the review questions. The remaining 37 articles were read in full and included in the review. The distribution of exclusions by criterion is summarised in Figure 2.

Table 1. Query construction.

"Retrofit*" OR "Refurbish*" OR "Renovat*"
AND
"Energ*"
AND
"Historic* Building*" OR "Heritage building*" OR "Cultural heritage"
AND
"Mediterran*" OR "Southern Europ*" OR "Ital*" OR "Span*" OR "Spain" OR "Greec*" OR "Greek*" OR "France" OR "French*" OR "Sloven*" OR "Croat*" OR "Alban*" OR "Turk*" OR "Malta" OR "Maltese*" OR "Cyprus" OR "Cypriot*" OR "Bosni*" OR "Montenegr*" OR "Portug*"

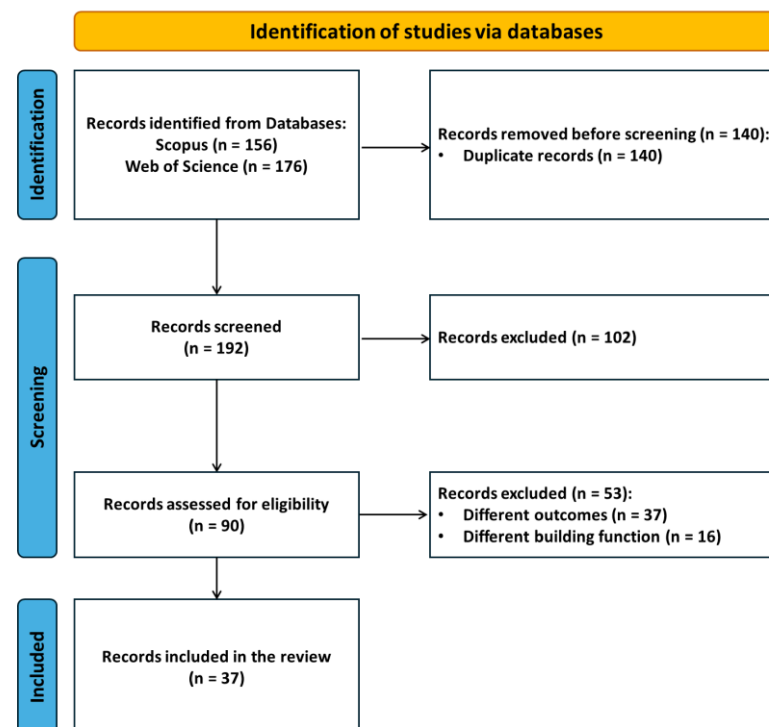


Figure 2. PRISMA flow diagram for study identification, screening, eligibility and inclusion.

After the full-text screening, all retrofit measures reported in the included studies were extracted and coded according to a common classification framework reported in Figure 3. This classification aimed to organise the heterogeneous terminology used in the literature into comparable intervention families. Measures were first divided into two main groups, passive strategies and active system strategies, and then by the targeted building element or system. Counts per category are reported in parentheses to indicate the number of articles addressing each intervention. Since several studies analyse combined retrofit packages, the categories are not mutually exclusive, and the values should be interpreted as frequencies of occurrence rather than additive totals.

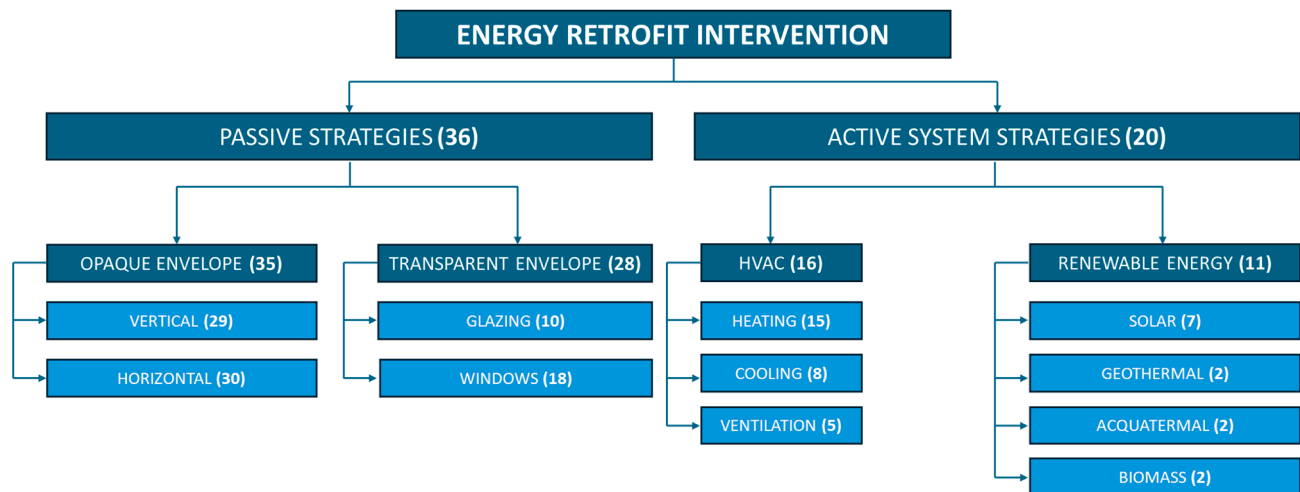


Figure 3. Classification of reviewed articles by intervention type (passive vs. active) and targeted building element/system; parentheses indicate the number of articles per category.

According to the table, passive strategies clearly dominate the corpus, being reported in 36 out of 37 studies. Opaque-envelope measures are the most frequent category, appearing in 35 studies, with a nearly balanced attention to horizontal components (30 studies) and vertical walls (29 studies). Transparent envelope measures are also widely represented, being reported in 28 studies, mainly through window interventions (20 studies) and glazing replacement or upgrading (10 studies). Active system strategies appear in 20 studies, mostly through HVAC-related measures (16 studies), while renewable energy systems are addressed in 9 studies. Within HVAC measures, heating-system interventions are the most recurrent, followed by cooling and ventilation strategies. Overall, Figure 3 confirms that the reviewed literature is primarily envelope-oriented, although active systems are frequently included as complementary measures for achieving deeper energy reductions.

3. Results

The Results Section is organised into three main subsections. The first (Section 3.1), an overview of the selected studies, provides an outline of the key topics addressed in each article. The second and third subsections examine the intervention categories identified through the classification scheme shown in Figure 3. In detail, Section 3.2, focused on passive strategies, is further divided into two subsections addressing opaque (Section 3.2.1) and transparent envelopes (Section 3.2.2), respectively. Within the opaque category, an additional distinction is made between vertical (Section Vertical) and horizontal (Section Horizontal) components. The final subsection of the results focuses on active system strategies (Section 3.3) and is structured into two sub-categories covering HVAC (Section 3.3.1) and renewable energy (Section 3.3.2). Several of the 37 reviewed articles address more than one category and are therefore discussed in multiple sections.

3.1. Overview of the Selected Studies

The classification framework reported in Figure 3 provided a first overview of the main intervention families addressed in the selected literature.

Looking at the set of retrofit interventions shown in each case, a classification was developed to group the articles by the combination of retrofit measures used. The results of this classification are three families of combinations of retrofit interventions: P (passive only), A (active only), and C (combination of passive and active measures). Based on this classification, it was possible to show that 51% of the examined studies present hybrid interventions that combine passive and active measures, 46% report exclusively passive

measures, and 3% focus exclusively on active systems. Going more in-depth to identify the most frequent combination of retrofit interventions in the European Mediterranean region, the three families have been divided into the following sub-categories:

- A1—HVAC + renewable energy;
- C1—opaque envelope + transparent envelope + HVAC;
- C2—opaque envelope + transparent envelope + HVAC + renewable energy;
- C3—opaque envelope + HVAC + renewable energy;
- C4—opaque envelope + transparent envelope + renewable energy;
- C5—transparent envelope + renewable energy;
- C6—opaque envelope + renewable energy;
- C7—opaque envelope + HVAC;
- P1—opaque envelope;
- P2—opaque envelope + transparent envelope.

The graph in Figure 4 shows the number of papers for each sub-category. Across the literature, two of the four most frequent combinations of retrofit interventions report only passive energy retrofit measures (P1 and P2), while the other two show a combination of passive and active energy retrofit measures (C1 and C2). This framework highlights that envelope retrofit interventions were the most reported energy retrofit measures for historical buildings.

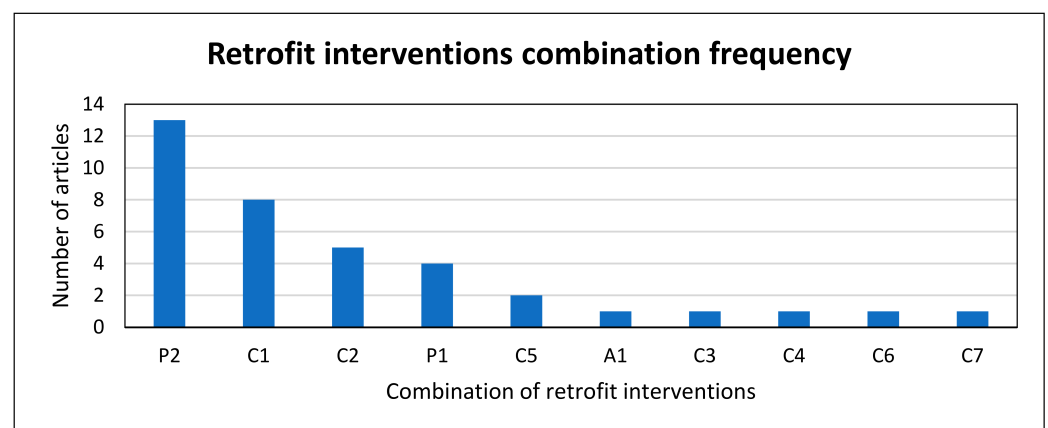


Figure 4. Number of articles per type of combination of retrofit interventions.

To move from article-level classification to the technical content of the reported retrofit measures, Figure 5 presents a set of Sankey diagrams. These diagrams summarise the occurrence of specific technologies and materials across the reviewed studies. The numbers in the Sankey diagrams do not indicate the number of articles but the number of times a given technology, material or retrofit option is reported in the extracted dataset. Therefore, one article may contribute more than one occurrence when it analyses multiple materials, positions or technical alternatives.

Figure 5a describes the vertical opaque envelope. A total of 58 occurrences are reported, with a nearly balanced distribution between internal applications (30 occurrences) and external applications (28 occurrences). Insulation panels represent the most frequent technological family, with 40 occurrences, while thermal plasters account for 18 occurrences. The most recurrent materials include aerogel, EPS, stone wool, hemp-lime, polystyrene, cork, wood wool and VIPs. This distribution highlights two main technological trends: the use of high-performance thin materials, such as aerogel and VIPs, to reduce thickness and invasiveness, and the use of thermal plasters or bio-based materials, such as hemp-lime and cork, to improve compatibility with traditional masonry.

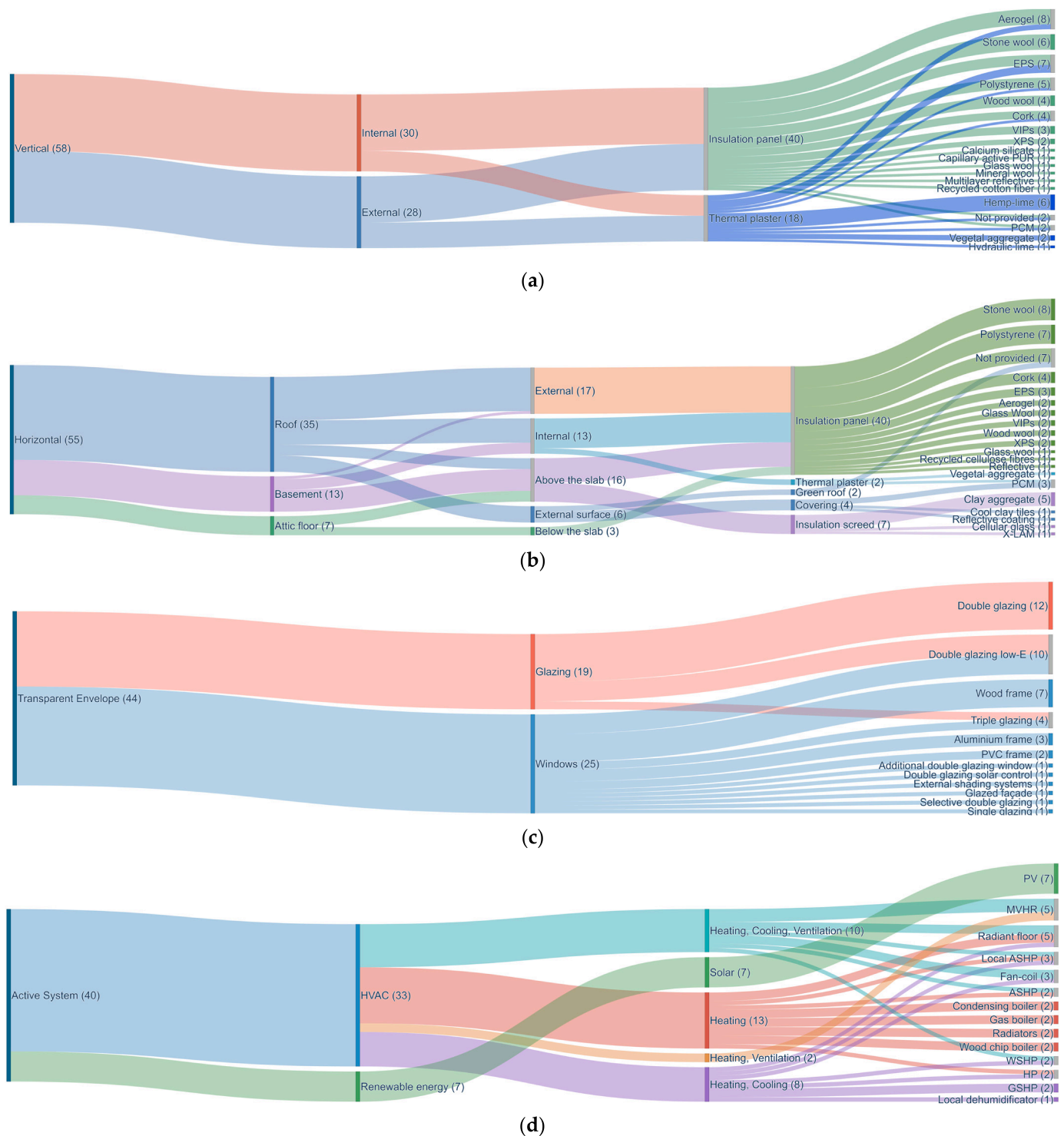


Figure 5. Sankey diagrams summarising the distribution of retrofit measures across the reviewed studies: (a) Vertical opaque envelope; (b) horizontal opaque envelope; (c) transparent envelope; (d) HVAC and renewable energy. Numbers refer to the occurrences of the items.

Figure 5b focuses on horizontal opaque components, with 55 occurrences. Roof interventions dominate this group, with 35 occurrences, followed by basement slabs and attic floors. Insulation panels are again the prevailing technology, with 40 occurrences, while insulation screeds, surface coverings, green roofs and thermal plasters are less frequent. The most recurrent materials include stone wool, polystyrene, cork, EPS, aerogel, glass wool and PCM-based solutions. The Sankey diagram shows that roof retrofit is a

key technical field in Mediterranean historical buildings, both for reducing winter losses and for improving summer performance through reflective materials, PCM layers, cool coverings or green-roof systems.

Figure 5c summarises transparent-envelope interventions, with 44 occurrences. Window-level interventions are slightly more frequent than glazing-only interventions, with 25 and 19 occurrences, respectively. Double glazing and low-emissivity double glazing are the dominant options, followed by wood-frame replacement, triple glazing, aluminium frames and PVC frames. The presence of secondary windows, solar-control glazing, selective glazing and external shading systems shows that transparent-envelope retrofit is often adapted to conservation constraints: where frame replacement is not acceptable, glazing substitution or reversible internal additions become preferable alternatives.

Figure 5d summarises HVAC and renewable energy technologies. HVAC measures account for 33 occurrences and mainly concern heating, combined heating–cooling systems, and integrated heating–cooling–ventilation systems. The most recurrent technologies include MVHR, radiant floors, local ASHPs, fan-coils, GSHPs, WSHPs, condensing boilers and biomass-based boilers. Renewable energy measures account for 13 occurrences. Solar technologies, mainly PV, are the most frequent, followed by aquathermal (two WSHPs), biomass and geothermal (two GSHPs) systems. These trends show that active strategies in historical buildings are not limited to conventional plant replacement, but increasingly involve electrification, controlled ventilation and locally available renewable sources, depending on visual, spatial and archaeological constraints.

Another aspect closely related to the type of retrofit measure is the scale of intervention, the types of data, and the geographic location of the buildings or group of buildings. In terms of scale, 65% of the reviewed papers analyse energy retrofit interventions at the single-building level, while 35% address groups of buildings. The latter category includes three main approaches: analyses at the district, neighbourhood or settlement scale; studies focused on architectural complexes; and works that extrapolate results from individual buildings or representative archetypes to the urban scale. In all cases, the results of retrofit interventions were simulated; only in a few cases was the monitoring campaign conducted for the calibration and validation of the model. The geographical distribution of the case studies provides an important contextual framework for interpreting the reviewed retrofit strategies. The analysed cases are unevenly distributed across the Mediterranean region: Italy accounts for the largest share, followed by Spain and Greece, while only isolated examples are reported in Albania, Portugal, France, Turkey, and Croatia (Figure 6).

This geographical framing is relevant because regulatory frameworks, heritage protection criteria, and conservation constraints differ between countries and directly influence the range of admissible retrofit measures. For this reason, Table 2 includes a “country” field for each article, allowing the reported interventions and outcomes to be related to their specific regulatory and conservation context. In addition, Table 2 contains for each article: location; scale of interventions; strategy (passive/active); combination ID; type of interventions; and energy impact reported outcomes. In the “Energy impact (%)” column, the reported values refer to specific intervention or strategy when declared; otherwise, the values refer to the sum of the intervention applied. Similarly, the table reports whether it refers to heating or cooling energy impact; when not specified, it refers to combined heating and cooling energy impact. Positive values indicate an increase in energy, while negative values indicate a reduction.

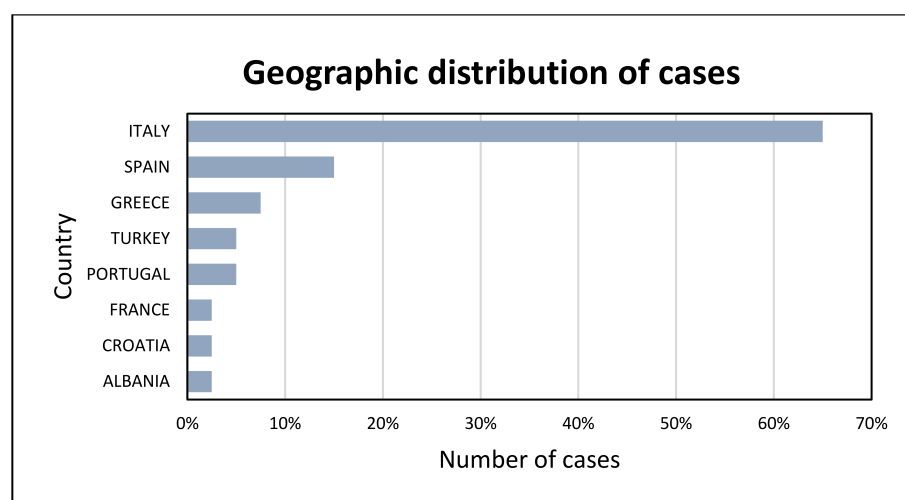


Figure 6. Distribution of reviewed cases within the European Mediterranean region.

Table 2. Classification of interventions and results.

Ref.	Location	Country	Scale	Strategies	Combination ID	Type of Interventions	Energy Impact (%)
[31]	Roma	Italy	Single building	Passive Active system	C4	Transparent envelope (windows) Renewable energy	Heating: +4 to −43 Cooling: +45 to −15
[32]	Reggio Calabria	Italy	Single building	Passive	P2	Opaque envelope (vertical, horizontal) Transparent envelope (windows)	−67
[33]	Venezia	Italy	Group of buildings	Passive Active system	C1	Opaque envelope (vertical, horizontal) Transparent envelope (windows) HVAC (heating)	Vertical: −55 Horizontal: −5 Windows: −5 Passive: −65 Heating System: −12
[34]	Mugla	Turkey	Single building	Passive Active system	C2	Opaque envelope (horizontal) Transparent envelope (glazing) HVAC (heating, cooling) Renewable energy	Passive + Active: −65 to −67
[35]	Seville	Spain	Single building	Passive	P2	Opaque envelope (vertical, horizontal) Transparent envelope (windows)	Heating: −32 to −54
[36]	Molfetta	Italy	Group of buildings	Passive	P2	Opaque envelope (vertical, horizontal) Transparent envelope (glazing)	Vertical: −5 to −13 Horizontal: −5 to −25 Glazing: −4 to −12

Table 2. Cont.

Ref.	Location	Country	Scale	Strategies	Combination ID	Type of Interventions	Energy Impact (%)
[37]	Palma de Mallorca	Spain	Single building	Passive	C1	Opaque envelope (vertical, horizontal)	Cooling: −28 Heating: −83
				Active system		Transparent envelope (windows) HVAC (heating, cooling, ventilation)	
[38]	Seville	Spain	Single building	Passive	C3	Opaque envelope (vertical, horizontal)	Passive (Heating): −23 Passive (Cooling): −1 Passive + Active: −42
				Active system		HVAC (heating, cooling, ventilation)	
						Renewable energy	
[39]	Cahors; Vitoria-Gasteiz	France; Spain	Single building	Passive	C1	Opaque envelope (vertical, horizontal)	Passive + Active (Heating): −72
				Active system		Transparent envelope (glazing) HVAC (heating, ventilation)	
[40]	Torino	Italy	Single building	Passive	P2	Opaque envelope (vertical)	Heating: −56
[41]	Aversa	Italy	Single building	Passive	P1	Opaque Envelope (Vertical)	Heating: −43
[42]	Monte Athos	Greece	Group of buildings	Passive	C1	Opaque envelope (vertical, horizontal)	Passive (Heating, B1): −18 Passive (Heating, B2): −52 Passive (Heating, B3): −92
				Active system		Transparent envelope (windows) HVAC (heating)	
[43]	Seville	Spain	Group of buildings	Passive	P2	Opaque envelope (vertical)	B1: −36 B2: −31 B3: −16
						Transparent envelope (windows)	
[44]	Monte Athos	Greece	Group of buildings	Passive	C2	Opaque envelope (vertical, horizontal)	Heating: −28 to −46
				Active system		Transparent envelope (windows)	
						HVAC (heating) Renewable energy	
[45]	Catania	Italy	Group of buildings	Passive	P2	Opaque envelope (vertical, horizontal)	Heating (B1): −21 Cooling (B1): −17 Heating (B2): −38 Cooling (B2): −39
						Transparent envelope (glazing)	
[46]	Monopoli; Maglie	Italy	Group of buildings	Passive	P2	Opaque envelope (vertical, horizontal)	Heating (B1): −53 Heating (B2): −53 Heating (B3): −36 Cooling (B1): −36 Cooling (B2): −38 Cooling (B3): −45
						Transparent envelope (windows)	

Table 2. Cont.

Ref.	Location	Country	Scale	Strategies	Combination ID	Type of Interventions	Energy Impact (%)
[47]	Coimbra	Portugal	Single building	Passive	C1	Opaque envelope (vertical, horizontal)	Passive—Heating: −30 to −48 Passive—Cooling: +33 to −31
				Active system		Transparent envelope (windows) HVAC (heating, cooling)	
[48]	Bolzano	Italy	Single building	Passive	C1	Opaque envelope (vertical, horizontal)	Passive + Active: −87
				Active system		Transparent envelope (glazing) HVAC (cooling)	
[49]	Palermo; Cagliari; Roma; Milano	Italy	Single building	Passive	P2	Opaque envelope (vertical, horizontal)	Passive (Case A): −41 to −57
						Transparent envelope (glazing)	Passive (Case B): −37 to −49
[50]	Krsan	Croatia	Group of buildings	Passive	C1	Opaque envelope (vertical, horizontal)	Passive + Active (Heating): −87 Passive + Active (Cooling): −75
				Active system		Transparent envelope (windows) HVAC (heating, ventilation)	
[51]	Catania	Italy	Single building	Passive	P2	Opaque envelope (vertical, horizontal)	Passive + Active (Heating): −30
						Transparent envelope (glazing)	Passive + Active (Cooling): −31
[52]	Monte Athos	Greece	Group of buildings	Passive	P2	Opaque envelope (horizontal)	Heating (B1): −37 Heating (B2): −62 Heating (B3): −92
						Transparent envelope (windows)	
[53]	Molfetta	Italy	Group of buildings	Passive	P1	Opaque envelope (vertical, horizontal)	Heating: −16 to −18 Cooling: −19 to −26
[54]	Perugia	Italy	Group of buildings	Passive	P1	Opaque envelope (horizontal)	Cooling: −32 to −51 Heating: +2
[55]	Coimbra	Portugal	Single building	Passive	C7	Opaque envelope (vertical, horizontal)	Passive (Heating): −18 to −49
				Active system		HVAC (heating)	Active (Heating): −25 to −30
[56]	Smirne	Turkey	Single building	Passive	C1	Opaque envelope (vertical, horizontal)	Passive: −37 to −76
				Active system		Transparent envelope (windows) HVAC (heating)	Active: +1 to −17 Passive + Active: −34 to −47
[57]	Perugia	Italy	Single building	Passive	P1	Opaque envelope (horizontal)	Heating: −42 Cooling: −97 Heating + Cooling: −43

Table 2. Cont.

Ref.	Location	Country	Scale	Strategies	Combination ID	Type of Interventions	Energy Impact (%)
[58]	Genova	Italy	Single building	Passive	C5	Opaque envelope (horizontal)	Passive: −11 to −32
						Transparent envelope (windows)	
				Active system		Renewable energy	
[59]	Roma	Italy	Single building	Passive	C5	Opaque envelope (vertical, horizontal)	Passive (Heating): −59
						Transparent envelope (glazing)	
				Active system		Renewable energy	
[60]	Verona	Italy	Single building	Passive	C2	Opaque envelope (vertical, horizontal)	Heating: −66 Cooling: −47
						Transparent envelope (windows)	
				Active system		HVAC (heating, cooling) Renewable energy	
[61]	Venezia	Italy	Single building	Active system	A1	HVAC (heating, cooling, ventilation) Renewable energy	Heating: −33 Heating + Cooling: −24
[62]	Popoli	Italy	Group of buildings	Passive	P2	Opaque envelope (vertical)	Heating: −10 to −42 Cooling: −7 to −16 Heating + Cooling: −9 to −44
						Transparent envelope (glazing)	
[63]	Caporciano	Italy	Group of buildings	Passive	C2	Opaque envelope (vertical, horizontal)	−42 to −53
						Transparent envelope (windows)	
				Active system		HVAC (heating) Renewable energy	
[64]	Roma	Italy	Single building	Passive	P2	Opaque envelope (vertical)	Passive (Heating): −64
						Transparent envelope (windows)	
[65]	Zena	Italy	Single building	Passive	C2	Opaque envelope (horizontal)	−28
						Transparent envelope (windows)	
				Active system		HVAC (heating, cooling) Renewable energy	
[66]	L'Aquila	Italy	Single building	Passive	C6	Opaque envelope (vertical, horizontal)	Passive (Heating): −52 Passive (Cooling): +34 Passive (Heating + cooling): −46
				Active system		Renewable energy	

Table 2. Cont.

Ref.	Location	Country	Scale	Strategies	Combination ID	Type of Interventions	Energy Impact (%)
[67]	Shkodra; Kruja	Albania	Group of buildings	Passive	P2	Opaque envelope (vertical, horizontal)	Passive (B1): −46
						Transparent envelope (glazing)	Passive (B2): −36 Passive (B3): −53

3.2. Passive Strategies

The classification of the articles shows that 36 of the papers included in the selection deal with passive strategies for retrofit interventions on historical buildings. Specifically, as seen in Figure 3, most strategies are related to both vertical and horizontal opaque construction elements.

3.2.1. Opaque Envelope

Vertical

The quantitative analysis of technical solutions for the opaque vertical envelope across the selected studies identifies specific performance benchmarks for both internal and external retrofit measures in the Mediterranean region.

Some studies explored the potential energy impacts related to the application of external insulation in historical buildings where façade constraints are hypothetically absent or sufficiently weak to allow the replacement of the external plaster. In a simulation of the Santa Marta district of Venice, assuming the absence of constraints on the façade, the authors showed that the maximum heating energy need savings achievable with external insulation applied to the whole vertical envelope, considering expanded polystyrene (EPS) panels, could reach 55% [33], leading also to a 52% decrease in operational energy costs. In another study related to an Art Nouveau building located in Reggio Calabria [32], characterised by typical façade decorations of that period, as the replacement of the original plaster was allowed, an external natural hydraulic lime TP was applied to the whole vertical opaque envelope. As a result, the authors highlight a 53% reduction in the external wall thermal transmittance.

A broader analysis conducted on Italian residential heritage in Palermo, Cagliari, Rome, and Milan [49], assuming no strict constraints on the external façades apart from possible plaster replacement, compared alternative retrofit options for the opaque vertical envelope. The selected measures consisted either of an internal insulation system with 60 mm EPS and a 50 mm air gap, or of 40 mm TPs applied on both the internal and external surfaces. These measures reduced the wall thermal transmittance from 1.04 W/(m²K) to 0.47 W/(m²K) in the case of internal insulation and to 0.68 W/(m²K) for TPs, leading to comparable primary energy savings, ranging from 8.5% to 26.5% for the former solution and from 8.1% to 25.1% for the latter. However, the authors also highlighted the potential risk of interstitial condensation when internal insulation systems are not installed with adequate techniques.

While the previous cases illustrate retrofit scenarios in which façade constraints were limited or absent, a different design approach emerges when the conservation value of external wall surfaces requires a differentiated treatment of the vertical opaque envelope. In buildings characterised by partially constrained façades, several studies assessed and compared alternative retrofit measures by differentiating the intervention according to the conservation significance of the various wall surfaces. In complex heritage assets such as the Waaghaus in Bolzano [48], the optimisation of the vertical opaque envelope involves a multi-faceted evaluation of insulation strategies to reconcile energy efficiency with heritage

preservation. Full internal insulation was discarded due to its significant negative impact on conservation compatibility with frescoes, while partial internal insulation, applied in the portion without historical value, was characterised by a negligible balance between conservation and energy demand reduction, regardless of the insulation material tested. The best balance between building performance and heritage conservation was observed with a partial external application, limited to approximately 64% of the surface area lacking historic value. According to this outcome, in two courtyard buildings, external insulation measures were applied only in the external walls facing the courtyard (courtyard block wall), as the ones facing the streets (street block walls) were under conservation constraints. In the case of Seville [38], where the original materials of the street block walls were not replaceable, a 4 cm panel of stone wool was applied in the courtyard block wall (covering 23% of the total external walls), reducing the thermal transmittance from $2.26 \text{ W}/(\text{m}^2\text{K})$ to $0.53 \text{ W}/(\text{m}^2\text{K})$. Similarly, in the case study of Campania [41], as the external granite stone cladding of the street block walls was not removable, the standard gypsum-lime plaster of the courtyard block wall was replaced with a 4–7 cm hemp-lime-based plaster, reducing the walls' thermal transmittance by between 54% and 66% and leading to a 43% reduction in heating energy consumption.

Other studies, instead, propose a combination of internal and external retrofit measures as the most effective solutions. In the case study of L'Aquila reported in [66], the application of only the external insulation was discharged due to the requested thickness, as well as the application of only the internal insulation due to interstitial condensation problems. Therefore, the authors proposed the implementation of both internal insulation (7 cm wood fibre panel) and external insulation (1.5 cm of aerogel-based plaster), reducing the heating demand by 52.3%, but increasing the cooling demand by 33.6%. Similarly, in the case study of Molfetta [53], a combination of internal and external insulation is proposed. Due to the presence of a characteristic external cladding, the vertical walls of the ground floor were insulated internally, while the ones of the upper floors were insulated externally. In both cases, aerogel boards were applied due to their limited thickness (about 40 mm), preferring them to vacuum insulation panels (VIPs) because they are easier to cut and adapt to irregular walls. As a result, the wall thermal transmittances were reduced by 83.5%, while heating and cooling reductions of 19.7% and 6.7% were achieved, respectively.

However, severe architectural constraints often preclude any external retrofit strategies, as documented in several studies, limiting the application of measures to only the internal surface of the opaque envelope. In the context of mono-family houses in Coimbra [47], a sensitivity analysis revealed a range of 60 mm to 70 mm to minimise the environmental impacts. Similarly, for traditional Albanian housing, where it is not possible to use external insulation for the historical building constraints, simulations showed that 100 mm of internal glass wool insulation could reduce both heating and cooling energy demands for a total reduction of between 28.8% and 44.5%, depending on the specific construction typology [67]. In the redevelopment project of Krsan Castle in Croatia [50], the need to make the interventions invisible and comply with strict conservation requirements required the installation of rock wool (5–10 cm) exclusively on the interior side so as not to alter the original appearance of the stone masonry. Although the insulation guaranteed a reduction in heating requirements, reducing the transmittance by up to $0.35 \text{ W}/(\text{m}^2\text{K})$, the study highlighted a critical issue related to the loss of effective thermal mass: internal insulation neutralises the inertia of the solid masonry, causing an increase in summer cooling requirements. In a further study [40], the Monastery of Santa Maria de Monfero was also assessed under a hypothetical Turin climate. The analysis considered 60 mm thick internal retrofit measures, including TP and dry counter-wall systems. The authors showed that the best measure, the counter-wall

with mineral wool + VIP configuration, reduces heating demand by 56%, followed by the aerogel TP with a heating demand reduction of 44%.

Horizontal

The retrofit measures targeting the horizontal opaque envelope were identified in 30 of the reviewed articles. The retrofit measures can include roof interventions, ground-floor slab interventions, or both. Overall, roof retrofits are more frequently explored than base-slab interventions, which are reported in only 11 articles. In roof retrofit interventions, insulation is installed either internally (intrados) or externally (extrados), depending on architectural constraints and accessibility. A further measure adopted is the ventilated roof system. Among the studies addressing roof measures, 40% focus on flat roofs and 60% on pitched roofs.

In highly protected historical buildings, where neither the external roofing materials nor decorated interior ceilings nor valuable floor finishes can be altered, roof and basement slab retrofit options become extremely limited and require measures compatible with strict conservation constraints.

In a residential building in Seville [38], 60 mm stone wool panels applied in the intrados of the flat roof contribute to a reduction of around 5% in the total annual energy consumption. Similarly, in a monumental building located in Genova characterised by protected wooden and brick vaults, the insulation was applied on the extrados, enabling a 5% reduction in annual energy needs [58]. In the case of Albanian houses, due to the presence of decorations both in the roof and in the intrados of the attic floor, 80 mm glass wool panels were installed on the extrados of the attic floor, reducing the total energy loads by 5% to 23.3% [67]. In another monumental residential palace in Palma de Mallorca [37], both the pitched and flat roofs were insulated internally with 100 mm mineral wool insulation panels, reducing the heating energy consumption by 5% while increasing the cooling energy consumption by 2%. Furthermore, to insulate the basement slab, the valuable floor finish was temporarily removed and subsequently repositioned to install an insulation layer of 90 mm, reducing the thermal transmittance by 73%. Conversely, in a residential building in Muğla (Turkey) [34], due to both the reversibility requirement of the intervention and the presence of a valuable ground-floor finish that could not be removed, the intervention was limited to the kitchen and bathroom areas, where such finishes were absent; in these portions, a 50 mm expanded clay aggregate layer was installed, resulting in modest total energy savings of 0.7% to 1.1%. Moreover, in the extrados of the attic slabs, a removable mattress made of 240 mm of recycled cellulose fibre was proposed, achieving an energy saving of between 1.6% and 1.8%.

In other case studies, conservation requirements do not entirely preclude envelope retrofitting but impose the preservation of the traditional chromatic and material character of the envelope finishing.

In the energy rehabilitation of the Corte Montresora [60], the roof was completely renovated using a wooden beam system with an insulation panel applied in the intrados, preserving the original tile finish to ensure visual and aesthetic continuity. Similarly, the ground floor was upgraded through a ventilated slab system with an insulation layer that incorporated traditional tiled flooring. These interventions led to a significant reduction in thermal transmittance (U-value): the roof's U-value decreased from 0.5 W/(m²K) to 0.33 W/(m²K), and the ground floor's U-value was improved from 0.65 W/(m²K) to 0.391 W/(m²K). Another case study concerns the replacement of the traditional clay roof tiles typical of the protected historic centre of Perugia with innovative "Cool Clay Tiles" [54], specifically developed to preserve the requirements of the local conservation context. For the top-floor apartment, i.e., the dwelling directly below the roof, this measure achieved a

51% reduction in cooling primary energy consumption, while causing a limited increase of less than 2% in winter heating demand and involving costs comparable to those of standard tile replacement.

Other studies report energy retrofit measures in buildings where opaque horizontal structures needed to be restored, maintaining both the original structural system and the chromatic and material character of the components.

In the attic apartment of a historic building in Perugia [57], due to the restriction against the use of reflective membranes on the external roof surfaces, the authors proposed a Cool-Green Roof measure, combining vegetative insulation with high solar reflectance. The compatibility of the vegetation roof system with aesthetic constraints allowed the annual primary energy to be reduced by 27%; moreover, the internal addition of 60 mm of fibreglass insulation reduced the primary energy by 42%. Other studies highlight the heat storage improvement of the roofs by including PCM as boards or coating of finishing elements [36,46,53]. In the case of Molfetta [53], due to the conservation of the wooden structure required, the roof terrace was insulated externally with a 30 mm layer of aerogel panels (high thermal performance at reduced thicknesses) installed beneath the external finishing tiles (improved through a PCM water-based solution), while preserving the original type of finishing surface and without altering the height of the terrace. This intervention reduced the roof's U-value by 81.9% and decreased heating and cooling consumption by 18.23% and 11.79%, respectively. In another similar case in Coimbra [47], the roof was completely replaced with a new one with the same wooden construction system and compatible finishing material to preserve the aesthetic value. The complete roof replacement enabled the integration of an EPS insulation layer into the roof structure, maintaining the original building height. The different thickness of insulation reduced energy needs for heating by 7% to 10% and for cooling by 8% to 16%. Similarly, in an Art Nouveau building in Reggio Calabria [32], the flat roof and the basement slab were insulated with 60 mm cork panels applied beneath the external finishing layer. Despite the conservation constraints, the chosen natural material was considered compatible with the original construction systems; moreover, its integration within the stratigraphy of the opaque components allowed the aesthetic appearance of the finishing layers to remain unaltered. As a result, the author highlights a thermal transmittance reduction of 86% for the roof and 78% for the basement slab. In another case in Rome [59], the use of natural-based insulation material integrated in the stratigraphy of the opaque horizontal elements allowed the conservation of the external appearance of the building. In the basement slab, the U-value was reduced from 1.10 to 0.34 W/(m²K) with 80 mm cork insulation panels between the screed and the structural layer. For the wood roof, the selected measure introduced an air cavity and 120 mm cork panels above the clay tiles, achieving a U-value of 0.32 W/(m²K). Similarly, in the Kršan Castle case study [50], rock-wool insulation was integrated into the roof and basement floor structures. The intervention, incorporated within a broader reconstruction and adaptive-reuse process, was considered compatible with conservation constraints as it remained invisible and non-invasive.

3.2.2. Transparent Envelope

Window interventions are present in 73% of the articles included in the review, and the measures depend primarily on whether conservation constraints allow any alteration of the façade's architectural appearance, i.e., replacement of original material. Where such alteration is permitted, the whole window may be replaced; where it is not permitted, interventions are limited to measures that do not modify the visible character of the façade, such as glass replacement or the addition of a secondary internal window.

Simulations of typical Italian residential buildings across four climate zones (Palermo, Cagliari, Rome, and Milan) revealed that substituting single-glazed windows with a double-glazed system (argon-filled), could lead to a reduction in thermal transmittance from $5.68 \text{ W}/(\text{m}^2\text{K})$ to $1.4 \text{ W}/(\text{m}^2\text{K})$ (75% of thermal transmittance reduction), achieving primary energy savings for heating of between 8.1% and 26.9% [49]. Similarly, in the Latin Quarter of Reggio Calabria, replacing existing windows and glass doors with triple-glazed units in PVC frames could allow a reduction in thermal transmittance by 65% and 61% for the frame and glass, respectively [32]. At Krsan Castle in Croatia, installing double-glazed energy-efficient windows resulted in a 15% reduction in heating demand and an 18% reduction in cooling demand [50]. Furthermore, passive cooling measures on the transparent envelope, such as the use of external shutters at Krsan Castle, were shown to block 80% of solar radiation and reduce cooling demand by 40% relative to the existing state [50]. Conversely, in buildings where window areas are relatively small, such as the Santa Marta district in Venice, the replacement of windows (achieving a U-value of $2.2 \text{ W}/(\text{m}^2\text{K})$) led to more modest district-level heating savings, with a reduction of approximately 4.5% in annual energy costs [33]. Similar outcomes are reported from a field assessment of a courtyard building in Seville [35], where only the external façade windows were replaced, showing still high heat losses related to the windows between 16% and 23%.

Other studies report outcomes only from glazing substitution intervention, due to aesthetic constraints, reporting thermal transmittance reduction and related energy saving.

In the case of Waaghaus in Bolzano, the use of double glazing allowed a thermal transmittance reduction of 48% [48]. Similarly, in the building located in Muğla (Turkey), adding secondary glazing to windows yielded a thermal transmittance reduction of 77% and an energy saving of up to 4.6% [34]. In Vitoria-Gasteiz and Cahors, the simple transition from single to efficient double glazing was shown to reduce heating electricity consumption by approximately 25% across different apartment typologies [39]. The case of Molfetta [36] reports a cooling energy demand reduction of 10% due to low-emissivity (low-E) double glazing filled with argon. In Catania, replacing standard 3 mm single glazing with selective double glazing (3-12-3 mm) reduced solar gains from 15,667 kWh to 6287 kWh, directly contributing to a 31% reduction in total cooling demand [51]. Another possible retrofit measure for the transparent envelope is shown in the case of the Albergo dei Poveri in Genova [58], as the addition of glazing panels in the original windows was technically unfeasible, and the windows were installed on the external edge of the wall; internal windows were added, reducing the building's energy needs by 28%. The new windows were accepted by heritage authorities as fully reversible.

Finally, in Rome, a curtain wall was applied in the building's southern exposure to test the energy benefit of double-skin façades (DSFs) with different types of glazing, e.g., double clear, double low-E, double reflective, triple thermochromic, double electrochromic, and double photochromic. Simulations demonstrated that low-E double glazing was the best measure to reduce the heating energy demand (43%), while double reflective glazing was identified as the most effective measure for the cooling season, providing a 15% cooling demand reduction [31].

3.3. Active System Strategies

3.3.1. HVAC

Interventions on air-conditioning, heating and MV systems are addressed in 16 of the articles included in the review. In most cases, system upgrades are implemented in combination with passive retrofit strategies, while only one paper focuses exclusively on measures at the active system level [61]. The reviewed literature highlights a shift toward the electrification of thermal services and the integration of advanced ventilation

strategies. Four articles report the impact related to the replacement of the heating system generators. In an apartment located within the UNESCO-listed historic centre of Coimbra (Portugal) [55], two systems were compared: an air-conditioner for space heating combined with an electric boiler for domestic hot water, and a gas boiler for both space heating and domestic hot water. The results showed that the former reduced final energy demand by 25–30% compared with the gas boiler. In a social housing building in Venice, the heating system was characterised by a centralised and obsolete configuration, with uninsulated distribution pipes and cast-iron radiators; given these conditions, the authors limited the intervention to the replacement of the heat generator, showing that the installation of a condensing boiler alone resulted in a 12% reduction in heating energy demand [33]. In a historical single-family house originally equipped with an oil-fired boiler, two retrofit options were compared: a condensing boiler and a decentralised air-to-air split HP. The results showed a reduction in heating demand of 25% for the HP measure and 12% for the condensing boiler. However, given the impossibility of altering the façade, the condensing boiler remained the most appropriate option under the existing conservation constraints [56]. In the refurbishment of the historic Haybarn Complex located within a mountain context in Greece, given the availability of surrounding forest resources, two biomass-based heating options were compared, namely a wood-fired boiler and a wood-chip boiler, both coupled with the same heat emission system consisting of radiators and radiant panels. The authors identified the wood-chip boiler as the more efficient measure, reporting biomass savings of about 45% compared with the wood-fired boiler [44]. Some studies focus on historical buildings originally lacking HVAC systems, for which different plant solutions are compared within the retrofit design process. The functional recovery of monumental buildings often requires the design of entirely new HVAC systems while strictly adhering to preservation constraints that exclude traditional external components like solar collectors or visible air-source units. For the Crucifers Convent in Venice [61], the hydrothermal potential of the surrounding lagoon was utilised as a primary renewable source through a reversible water-to-water heat pump, a measure selected to bypass restrictions on solar installations and prohibitions against groundwater extraction linked to subsidence fears. This system, which integrates fan coils discreetly embedded within furnishings to respect architectural integrity and painted surfaces, achieved primary energy savings exceeding 20% compared to traditional gas boiler and air-cooled chiller measures, with a renewable energy quota averaging 33%. For the renovation of the Castle of Zena (characterised by residential function together with hospitality and events) [65], in spite of the high thermal mass of the walls, the necessity of an active cooling plant was pointed out. Hence, the authors prioritised the implementation of HPs, a choice driven by the need to avoid invasive ductwork associated with “all-air” systems and the visual impact of wind or solar technologies. Testing two different measures, namely air-source and water-source (leveraging an existing historical well), the study shows that the latter reduces the primary energy consumption 28% more than the former. Following a similar approach, in the case of a historical residential complex in Verona [60], a traditional gas-based boiler with radiators coupled with a multi-split system is compared with a ground source heat pump (GSHP) coupled with radiant floor panels.

Other studies, instead, focus on how the original HVAC system could be refurbished. In a multi-family historical building located in Seville, the study shows how a decentralised plant configuration based on apartment-level split units can be replaced by a centralised system built around a single air-to-water heat pump with electric backup, serving a hydronic distribution network with fan-coil terminals. This case is particularly relevant for heritage retrofits because it illustrates how plant-system upgrading can improve overall compatibility, rationalise energy supply at the building scale, and reduce the need for

invasive envelope alterations in protected residential buildings [38]. Similarly, in two traditional Anatolian houses [34], the study compared alternative HVAC upgrade strategies starting from an existing configuration based on a biomass stove and conventional split air-conditioning units. The analysed options included high-efficiency split systems, variable refrigerant flow systems, and a GSHP, showing a primary energy reduction of 31.7%, 44.5%, and 52.3%, respectively. The authors highlight that, in houses with private gardens or courtyards, GSHP systems represent a highly effective option, as the ground works required for buried heat exchangers can be accommodated within the property without altering the protected architectural character of the building.

Finally, two studies analyse the implementation of mechanical ventilation with heat recovery (MVHR). A fundamental prerequisite for the effectiveness of MVHR is the drastic improvement of building airtightness; as noted in the study of Krsan Castle [50], the system offers no energy advantage if uncontrolled air infiltration is not significantly reduced. As a matter of fact, experimental data from traditional residential buildings in the city of Vitoria-Gasteiz [39] estimated a reduction of approximately 10% in heating demand when MVHR is coupled with improved airtightness. However, the authors highlight that the primary energy balance could be negative based on the specific location.

3.3.2. Renewable Energy

Renewable energy sources are introduced not as foreign additions but as integrated components designed to preserve the material integrity and visual authenticity of historical buildings.

In contexts where local regulations prohibit the installation of conventional solar panels in order to avoid visual pollution, research has explored “mimetic” solutions. In Rome [31], photovoltaic technology has been integrated through semi-transparent glazing incorporated into double-skin façades (DSFs), enabling energy conversion while preserving the original architectural image. Similar approaches have been proposed in L’Aquila [63], in the rehabilitation of the former San Salvatore Hospital, where monocrystalline silicon modules integrated into glazing were considered for flat roofs, while flexible thin-film modules were proposed for pitched roofs, positioned so as to respect the profile and colour of the existing roofscape. In the Garbatella district of Rome [59], the strategy instead involves placing photovoltaic cells on non-visible roof portions or exploiting glazed surfaces of conservatories to be restored, as hypothesised for the Albergo dei Poveri in Genoa [58]. In contexts of extreme isolation, such as the Hilandar Monastery on Mount Athos [44], photovoltaic modules are installed at an appropriate distance from the monumental complex, in isolated areas, so as not to interfere with the aesthetic character of the site.

In the same isolated context, also characterised by the strong presence of local natural resources [44], the use of biomass sources is explored as the primary heating source. The use of wood-chip boilers, fuelled by timber obtained from the maintenance and clearing of woodland owned by the monastery, makes it possible to meet thermal demand in full compliance with environmental protection requirements and the site’s energy autonomy.

Finally, some articles highlight how the implementation of HPs could enhance environmental renewable energy, reducing the net fossil fuel consumption. In cases where the site offered sufficient ground availability for excavation and the installation of buried heat exchangers, GSHP systems emerged as a more energy efficient measure than traditional multi-split systems, as reported in the case of “Corte Montresora” [60] complex and traditional Anatolian houses [34]. In some cases, the renewable resource is identified directly on site. In the rehabilitation of the “Convento dei Crociferi” [61], the impossibility of using the ground for geothermal systems, together with the prohibition on installing solar panels, led to the adoption of hydrothermal energy. The system exploits lagoon water drawn

from the Rio dei Gesuiti and coupled with an HP, ensuring energy savings of more than 20% compared with conventional systems. In the Zena Castle [65], landscape constraints excluded both wind and solar energy, leading to the adoption of HPs using existing well water as a thermal source, with a significant increase in the seasonal efficiency with respect to traditional air source heat pumps (ASHPs).

4. Discussion

As discussed in the previous section, conservation constraints do not necessarily prevent energy improvement; rather, they change the location, depth, reversibility and material logic of the intervention. Measures that are effective in ordinary buildings may be unsuitable when they alter façades, decorative layers, stone surfaces, roofscapes or historic urban views. Therefore, the most robust strategies are those that combine selective envelope improvement, passive cooling, efficient systems and hygrothermal risk control according to the degree of heritage transformability [33,38,39,45,63].

A first cross-cutting finding concerns the opaque vertical envelope. External insulation is thermally more advantageous than internal insulation because it preserves the coupling between indoor spaces and masonry thermal storage. This is particularly relevant in Mediterranean climates, where massive wall contributes to support night-time cooling strategies [45,51]. For this reason, several studies prioritise at least a partial external insulation of the vertical opaque envelope, applied only on surfaces free from frescoes, decorations, or external finishes that are not replaceable [48,63], often located in the street block walls [38,41]. In case of façades where the replacement of the original plaster is allowed, the common measure is the thermal plasters (hemp-lime or EPS additives) that respect the traditional chromatic and material character [46,51,62]. The thermal transmittance of the walls can be further reduced by applying thin aerogel panels or VIPs before the thermal plaster layer [46].

However, as external surfaces of historical buildings cannot often be modified, internal insulation is frequently proposed as the main alternative. As reported from the reviewed studies, high-performance internal insulation panels, such as EPS-based panels, can substantially lower heating demand [40,49,50,53,67]. To minimise the spatial impact, aerogel panels or VIPs were adopted, which guarantee a high reduction in thermal transmittance with reduced thicknesses (15–30 mm). However, in Mediterranean climates, internal insulation also reduces the effective contribution of the historic wall's thermal mass to indoor conditions, potentially increasing summer peak temperatures and cooling demand [40,50,66,68]. Against this backdrop, internal application of PCMs in the form of thermal plaster or thin panels reveals lower summer peak temperatures and cooling demand increases than high-performance panels [33,40]. Furthermore, a relevant connected problem is that internal insulation, during winter, reduces the drying potential of the wall towards the indoor environment, increasing the risk of moisture accumulation from wind-driven rain, rising damp or indoor vapour diffusion, leading to interstitial condensation, mould growth, and material decay. Dang et al. [17] and Leonardi et. al. [69], clarify this mechanism by distinguishing vapour-tight systems, such as EPS-based solutions, from capillary-active systems, such as calcium silicate boards and plasters. Vapour-tight systems restrict inward moisture transport and may increase moisture-related risks, whereas capillary-active systems promote vapour and liquid moisture redistribution and behave more similarly to uninsulated masonry. Furthermore, moisture content increases the thermal conductivity of the material, affecting the thermal transmittance calculated in dry conditions [40]. In this sense, thermal plasters, besides generally having higher thermal conductivity with respect to vapour-tight systems [40], maintain a better hygrothermal interaction with traditional masonry due to their higher thermal inertia. In particular, hemp-lime plaster is suitable to

balance winter energy reduction, summer wall performance improvement and mould risk compared with the traditional plasters [41].

Horizontal opaque components, especially roofs, emerge as one of the most promising intervention surfaces in Mediterranean historical contexts when façade interventions are restricted. Roofs are often responsible for significant summer heat gains and winter energy loss. The insulation is mainly placed externally under the original tiles, removed and then repositioned or replaced; otherwise, the attic floor could be insulated, avoiding weighing down the historic wooden structures [33,44,46,59]. Concerning the summer performance, the use of PCMs is also documented in [36,46,53] to increase the thermal inertia effect of roofs characterised by low thermal mass. Moreover, the reviewed studies on cool clay tiles and Cool-Green Roofs show that passive roof technologies can substantially reduce overheating and cooling demand while limiting visual impact [54,57]. These results indicate that roof retrofits can serve as climate-adaptation and energy-saving measures.

Transparent envelope interventions also show strong seasonal trade-offs. Low-emissivity glazing is effective in reducing winter heat losses, while selective or reflective glazing may be more advantageous under cooling-dominated conditions [31,35,39]. Aruta et al. [31] show that in double-skin façade configurations, low-E glazing performs best in winter, while reflective glazing provides better summer results. This confirms that window and façade solutions should not be assessed through heating demand alone. In historical buildings, replacement of original windows may also conflict with conservation requirements related to frame material, subdivision, depth, reflectance and craftsmanship. Reversible secondary glazing or internal additional windows can therefore be preferable where original frames must be preserved [34,39,58,70]. Increasing airtightness and improving glazing may reduce heat loss; however, proper ventilation strategies should be considered to manage indoor humidity, CO₂ concentration and mould risk [34,35,71,72].

Overall, considering historical buildings where interventions on the envelope are generally limited to local and low-impact measures, opaque envelope interventions (P1) reveal an energy demand reduction of between 6 and 18% (heating), and 19 and 26% (cooling) [41,53], while the sum of opaque and transparent envelope measures (P2) achieves a reduction of 36–63% (heating) [40,52,64,67]. In buildings with a lower degree of constraint, the sum of the passive strategies (P2) provided energy demand reductions of between 10 and 53%, and 7 and 45% for heating and cooling, respectively [46,54,62].

Building on these results, active systems and renewable integration emerge as the main pathway for moving from moderate demand reduction to deeper decarbonisation when envelope interventions are limited by heritage constraints [34,38,40,61,65]. The reviewed studies show three recurrent trends: replacing fossil-fuel boilers with high-efficiency heat pumps, integrating mechanical ventilation to improve indoor air quality and moisture control, and exploiting renewable or locally available energy sources where compatible with conservation requirements [34,38,61,65]. Evidence from other case studies confirms that heat pumps, hybrid HVAC configurations and renewable-based systems are particularly relevant when façade insulation, window replacement or solar technologies are constrained by heritage protection [38,61,65]. Overall, passive–active packages (C1 and C2) reach energy demand reductions of up to 87% and 75% for heating and cooling, respectively [33,34,37,50]. However, plant-based solutions may conflict with conservation through outdoor units, ducts, boreholes, plant rooms, acoustic impacts and maintenance needs [38,61,65].

Overall, the cross-cutting evidence indicates that Mediterranean historical building retrofit should be guided by three simultaneous performance criteria: heating reduction, cooling resilience and hygrothermal safety. Heating reduction remains necessary because many historical Mediterranean dwellings are cold in winter and rely on inefficient systems or intensive heating use [35]. Cooling resilience is equally important because climate projec-

tions and recent simulations show decreasing heating needs but increasing cooling demand, especially in buildings with low thermal inertia or poorly protected roofs [36,54,57,62]. Hygrothermal safety is the third criterion because several energy measures, especially internal insulation and airtightness improvement, modify the moisture balance of traditional walls and indoor environments [17,35,40]. These three criteria also suggest that retrofit assessment should increasingly move from isolated case studies to the urban scale. In historical districts, heating demand, cooling resilience and hygrothermal behaviour are influenced not only by individual buildings but also by compactness, mutual shading, orientation, courtyard morphology, roof exposure and urban heat island effects [33,36,43,63]. Parametric methods and co-creation approaches can therefore support the grouping of buildings into representative typologies, the prioritisation of retrofit scenarios and the selection of solutions that are technically effective, locally feasible and compatible with heritage values [33,39,63].

5. Conclusions

This review analysed energy retrofit strategies for historical buildings in the European Mediterranean context, to identify the most recurrent combination of interventions, assessing their energy impacts and clarifying how conservation constraints influence the selection of compatible measures. The findings provide evidence-based answers to the research questions formulated at the beginning of the study.

Regarding RQ1, the reviewed literature shows that retrofit strategies are mainly envelope-oriented. Passive measures, especially those involving opaque and transparent components, represent the most recurrent approach and are often combined with HVAC upgrades and renewable energy systems. Wall insulation strategies generally achieve heating-demand reductions of about 20–56%; horizontal-envelope measures usually provide more limited heating-demand reductions (5–18%) but can significantly improve summer performance. Window retrofit energy impacts report reductions of about 15–25% for heating and 10–31% for cooling. Combined passive–active packages reach reductions of up to 87% for heating and 75% for cooling. The Sankey diagrams helped to clarify the technological trends behind these results. For the opaque vertical envelope, the reviewed studies show a balance between internal and external applications, with high-performance panels, thermal plasters, aerogel, VIPs and bio-based materials among the most recurrent solutions. For horizontal components, roof interventions are particularly relevant, especially in relation to summer performance. Transparent-envelope measures mainly include window replacement, glazing substitution and secondary windows, while active strategies increasingly involve heat pumps, mechanical ventilation and solar PV.

Regarding RQ2, the review shows that conservation constraints do not exclude energy retrofit, but they strongly affect the admissibility, position, thickness, reversibility and material compatibility of the interventions. External insulation is generally more effective from a thermal point of view, but it is often limited by the need to preserve façades and historical surfaces. Internal insulation is therefore frequently adopted as a compatible alternative, although it requires careful assessment because it may reduce the contribution of masonry thermal mass, increase summer overheating risk and alter the hygrothermal balance of historic walls. For this reason, vapour-open, capillary-active and hygroscopic materials, including thermal plasters and bio-based systems, emerge as relevant options for balancing energy improvement and material compatibility. Overall, the review indicates that retrofit design for Mediterranean historical buildings should not be guided only by energy-demand reduction. Three performance criteria should be considered simultaneously: heating reduction, cooling resilience and hygrothermal safety. This is particularly important in Mediterranean climates, where buildings must respond to winter discomfort,

increasing cooling demand and moisture-related risks associated with internal insulation, airtightness improvement and window upgrading.

This review provides a structured framework for interpreting energy retrofit strategies for historical buildings in the European Mediterranean context, linking passive and active measures to different degrees of conservation constraint. Its main contribution lies in supporting the preliminary identification of compatible retrofit pathways according to the architectural and material transformability of the building. However, the reviewed literature still lacks systematic assessments of economic performance, indoor comfort, and post-retrofit monitoring, limiting the comparison of retrofit strategies beyond energy savings. Future research should therefore investigate the real cost-effectiveness, life-cycle impacts, and hydrothermal comfort, giving a comprehensive assessment of the proposed retrofit measures.

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Nomenclature

ASHP	Air source heat pump
DSF	Double-skin façade
EPS	Expanded polystyrene
GSHP	Ground source heat pump
HP	Heat pump
HVAC	Heating, ventilation and air-conditioning
Low-E	Low-emissivity
MV	Mechanical ventilation
MVHR	Mechanical ventilation with heat recovery
PCM	Phase change material
PV	Photovoltaic
TP	Thermal plaster
VIP	Vacuum insulation panel
WSHP	Water source heat pump

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