Historic buildings resilience: A view over envelope energy retrofit possibilities.

Magda Posani, Maria Do Rosário Veiga and
Vasco Peixoto De Freitas

January 2, 2019

Historic buildings resilience: A view over envelope energy retrofit possibilities.

Abstract

2018 is the European Year of Cultural Heritage, officially defined by the European Parliament and Council in May 2017. Therefore the need of defining and promoting good practices in conservation and enhancement of historic buildings in Europe is much a current issue.
In the last decades, an increasing attention has been paid to the improvement of energy performances and indoor thermal comfort in existing constructions to guarantee their reuse and keep them alive. Moreover, historic buildings, by definition durable and resilient constructions, should be prepared for the new challenges of climatic changes.
The present study considers strategies, technologies and materials proposed in literature for historic buildings energy and thermal retrofit, focusing particularly on envelope refurbishment interventions. The suitability of the solutions for preserving historic valuable constructions is also accounted, mainly via considering the principle of authenticity and vapour permeability for compatibility. The efficacy of the interventions, in terms of energy savings, is then investigated.
Results show that existing solutions can lead to significant decreases in buildings energy consumption, 22% to 51% averagely, but only part of them appears suitable for historic buildings preservation.

Keywords: Cultural heritage, Energy efficiency, Envelope retrofit, Resilience, Restoration, Building preservation, Sustainability.

1. Introduction

In the field of historic heritage reuse and conservation, an increasing attention has been paid to the improvement of energy performance and indoor thermal comfort of existing constructions in the last decades (Martínez-Molina *et al.*, 2016). Such enhancements can be obtained via energy-retrofits of the built heritage, interventions that play a key role in reducing global energy consumptions (Brandt, 2017) and which may help buildings to face the serious threats imposed by climate changes.

The present study aims to analyse the solutions proposed in literature for the aforementioned interventions, focusing particularly on envelope thermal retrofitting solutions.

The investigation is organized in three parts: the first considers the solutions for historic buildings energy efficiency improvement defined in literature; the second examines historic envelope retrofitting solutions, their frequency in the research scenario and their suitability for historic constructions preservation, mainly considering vapour permeability aspects. The last part investigates the energy savings provided by retrofitting interventions according to experiences and studies developed in Europe in recent years.

2. Historic buildings energy retrofit and resilient design

2.1. Existing buildings resilience to climate change

Climate has already suffered a severe change all over the world and the situation is expected to get worse and lead towards higher temperatures during summer, precipitation pattern changes, local winds intensification and more intense or even frequent extreme events (Mosoarca *et al.*, 2017). Therefore, retrofit interventions designed for adapting existing buildings to future climate changes are definitely needed but they are also very difficult to be defined as high uncertainties occur when accounting the future behaviour of the weather (Nik and Arfvidsson, 2017).

Nik *et al.* (2016) have already studied the problem of buildings retrofit for facing future climatic conditions in the Swedish environment. The researchers used a statistical method for assessing the effects of several interventions while considering different global climate models and their uncertainty factors. The results show that the improvement of windows and envelope insulation was the most effective solution among all the ones considered.

According to such outcomes, envelope energy retrofitting measures can be accounted to offer efficient solutions for climate change adaptation of existing buildings.

2.2. Energy retrofitting solutions in literature

The literature review carried out in the area of energy efficiency retrofit of historic buildings has shown the existence of a wide range of possible interventions that are here classified in two categories: active and passive strategies.

Active strategies include all the solutions related to the use of:

- Renewable energy technologies (RETs), e.g. solar thermal and photovoltaic systems (Cellura *et al.*, 2017);
- Modern lighting and electrical appliances, such as energy saving lighting and low consumption electrical devices (Rosales Carreón, 2015);
- High efficient HVAC systems, solution that is very effective when the previous automatic regulation is poor or absent, e.g. the case of heaters without thermostatic valves (Rosales Carreón, 2015);
- Control devices for smart management of energy, designed to optimize the energy use according to users' routine and adaptive comfort conditions (Galatioto, Ciulla and Ricciu, 2017).

Passive strategies are instead associated to:

- Natural ventilation, that can provide passive cooling and that is very suitable for climates with long lasting high temperature periods (Galatioto, Ciulla and Ricciu, 2017);
- Organisational-behavioural measures directly adopted by building users (Rosales Carreón, 2015);
- Buildings envelope retrofits that can be obtained via interventions on insulation, thermal inertia, windows, shading devices, thermal bridges and air tightness (Andra Blumberga *et al.*, 2016).

The presence of an extended variety of interventions for energy efficiency improvement in historic constructions is clear. Nonetheless, only the solutions related to "Building envelope retrofit" are considered in the following parts of the study as they are expected to be effective for achieving both buildings adaptation to climate change (Nik et al., 2016) and energy efficiency improvements.

2.3. 1. Preservation aspects

Retrofitting the historic heritage is a great challenge as the distinctive character of each building has to be protected and the aesthetic impact of interventions should be carefully minimized. What is more, compatibility and reversibility requirements must be met in order to guarantee the preservation of original materials.

In this scenario, it is possible to define solutions that are generally more adequate than others. In literature such suitable interventions are outlined (Pickles, Brocklebank and Wood, 2010; Rosales Carreón, 2015) as follows:

- Windows: for the principle of authenticity, the preservation of glasses and frames is fundamental for preserving the original appearance of the construction;

- Walls: the appearance of external walls is usually one of the most important aspects of a historic building and it contributes to create the unique and local character of the construction. For these reasons, it is often preferable not to intervene on outdoor facades. Indoor surfaces are more likely to be suitable for being retrofitted, especially when a complete internal re-plastering is required. It has to be accounted that dimensional changes may be unacceptable at window and door openings and where original surfaces details are valuable;

- Floors: generally floors materials should not be lifted because of the damage that is inevitably caused, exceptions can be made when floors have to be replaced;

- Roofs: unless there has been substantial water leakage, roofs structures are usually in good conditions because of the generous amount of ventilation through their components. Therefore, this characteristic should not be altered;

- Insulation materials: preserving components breathability is a key element for ensuring durability in all traditional constructions. It is thus appropriate to adopt materials characterized by higher vapour permeability than the original, adjacent ones. What is more, natural fibers have to be preferred as they allow air and moisture vapour to slowly pass through, thus minimising the danger of condensation. They can also absorb moisture and release it again when the air is drier, this moisture-buffering behaviour is typical of hygroscopic materials and, in many historic buildings, it can help avoid moisture related problems.

3. Energy retrofit solutions for historic buildings envelope

In this section of the study, the solutions found for each category of envelope retrofit interventions (walls, roofs, floors, windows, air tightness, thermal bridges and shading devices) are reported and organized according to the frequency of their use in literature. The frequency is accounted as follows: when a solution is considered in a general study or review, such result is considered once; when an analysed paper contains one or more case studies, the solution frequency is accounted once more every time such measure is considered in a different case study.

As long as the preservation aspects are concerned, solutions with low water vapour resistances ($\mu \leq 15$) are here considered compatible with historic materials and, among them, hygroscopic solutions are highlighted.

3.1. Walls

The most common interventions considered for walls energy retrofit are the addition (or substitution) of insulation and the increase of thermal inertia, via PCM (Phase Change Materials) plaster adoption; both interventions can be applied to the internal and external surfaces of vertical components.

1. Internal insulation solutions: 59 mentions found in literature (n=59, in Ascione, De Rossi and Vanoli, 2011; Pickles, Brocklebank and Wood, 2010; De Berardinis *et al.*, 2014; Ascione, Bianco, *et al.*, 2015; Ascione, Cheche, *et al.*, 2015; Dalla Mora *et al.*, 2015; Blumberga *et al.*, 2016; Mancini *et al.*, 2017; Biseniece *et al.*, 2017; Cirami *et al.*, 2017; Di Ruocco, Sicignano and Sessa, 2017).

The results are shown in Fig.1. The most common solutions involve the use of Expanded Polystyrene (EPS) based components, thermal insulating plasters and mineral wool.

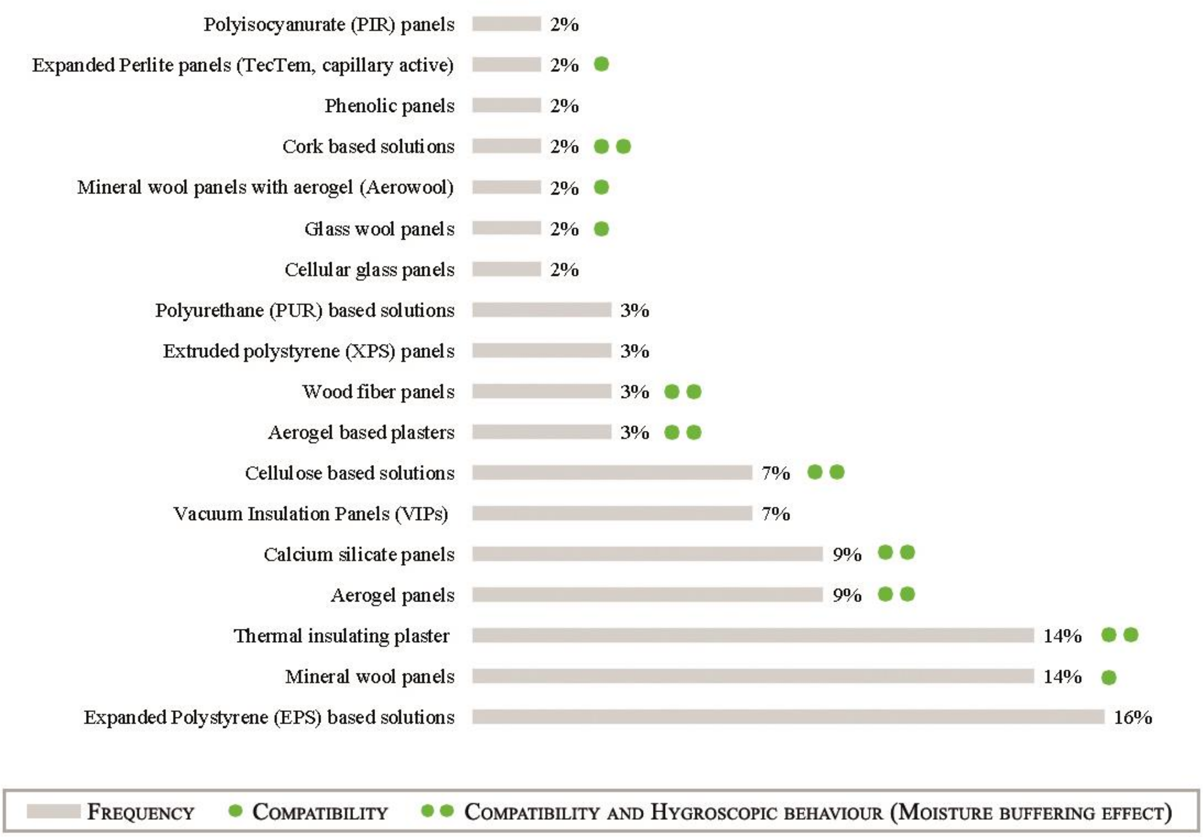

Figure 1: Internal insulation solutions for walls in historic buildings (frequency in literature, compatibility and moisture buffering effect).

2. External insulation solutions: 15 mentions found in literature (n=15, in Pickles, Brocklebank and Wood., 2010; De Berardinis *et al.*, 2014; Ascione, Cheche, *et al.*, 2015; Rosales Carreón, 2015; Blumberga *et al.*, 2016; Cornaro, Puggioni and Strollo, 2016; Baggio *et al.*, 2017; Mancini *et al.*, 2017; Roberti *et al.*, 2017). The results obtained for external insulation solutions are shown in Fig.2. Mineral wool panels and EPS based components are found to be the most popular solutions.

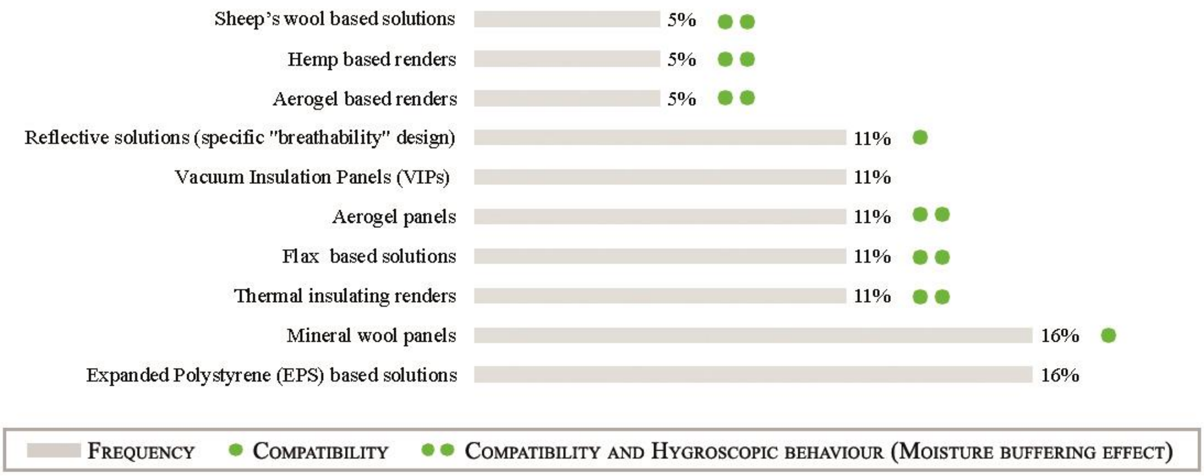

Figure 2: External insulation solutions for walls in historic buildings (frequency in literature, compatibility and moisture buffering effect).

3. PCM (Phase change material) plasters: two solutions found (n=2, in Ascione, Bianco, *et al.*, 2015). The results, obtained via dynamic simulations for a specific case study, indicate that PCM plasters provide relevant energy savings only in summer, as shown in table 1.

Table 1: PCM plasters efficiency, from Ascione *et al.*(2014) , compatibility and moisture buffering effect.

Wall ext.			
	MATERIAL	●● PCM based render (3cm)	- melting point of 32 °C
	ENERGY SAVINGS	0%Winter, 8.5% Summer	
Wall int.			
	MATERIAL	●● PCM based plaster (3cm)	- melting point of 27 °C
	ENERGY SAVINGS	0%Winter, 8.3% Summer	

●● COMPATIBILITY AND HYGROSCOPIC BEHAVIOUR (MOISTURE BUFFERING EFFECT)

3.2. Roofs

The most common intervention for roofs energy retrofit is the addition or substitution of insulation (n=21, in David Pickles, 2010; Ascione, Bianco, *et al.*, 2015; Ascione, Cheche, *et al.*, 2015; Dalla Mora *et al.*, 2015; Andra Blumberga, *et al.*, 2016; Baggio *et al.*, 2017; Cirami *et al.*, 2017; De Fino *et al.*, 2017; Mancini *et al.*, 2017; Roberti *et al.*, 2017). The most widely adopted materials are mineral wool and cellulose, as shown in Fig.3.

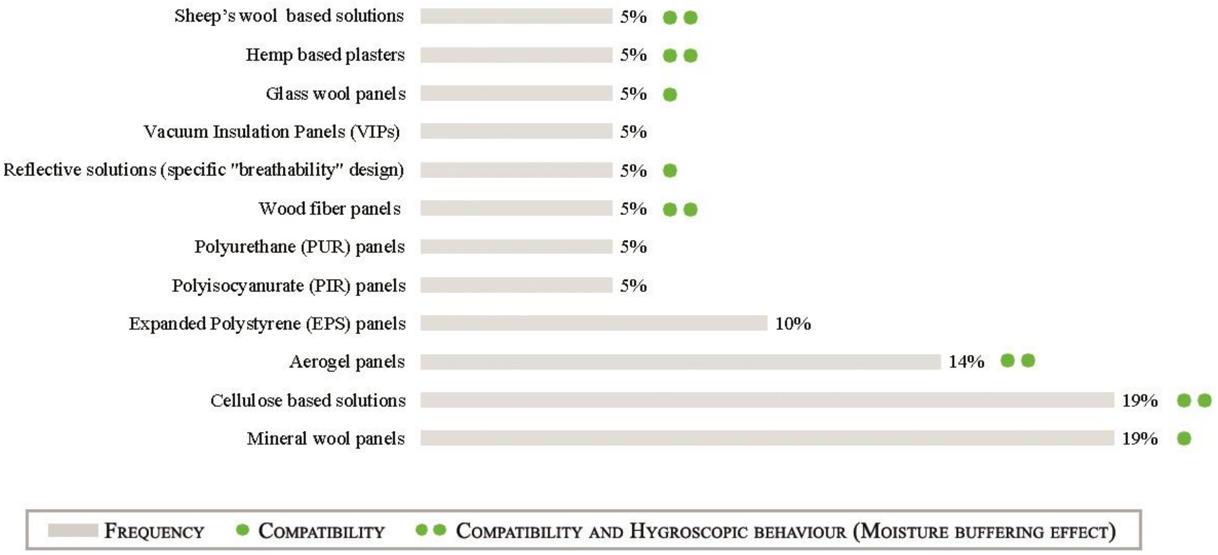

Figure 3: Roof insulation solutions in historic buildings (frequency in literature, compatibility and moisture buffering effect).

3.3. Floors

The most common intervention for floors retrofit is the addition (or substitution) of insulation (n=16, in Pickles, Brocklebank and Wood, 2010; Rosales Carreón, 2015; Blumberga *et al.*, 2016; Cornaro, Puggioni and Strollo, 2016; Biseniece *et al.*, 2017; Di Ruocco, Sicignano and Sessa, 2017).

The results obtained from the review are presented in Fig.4. Cellulose, hemp and wood fibers are the most mentioned materials.

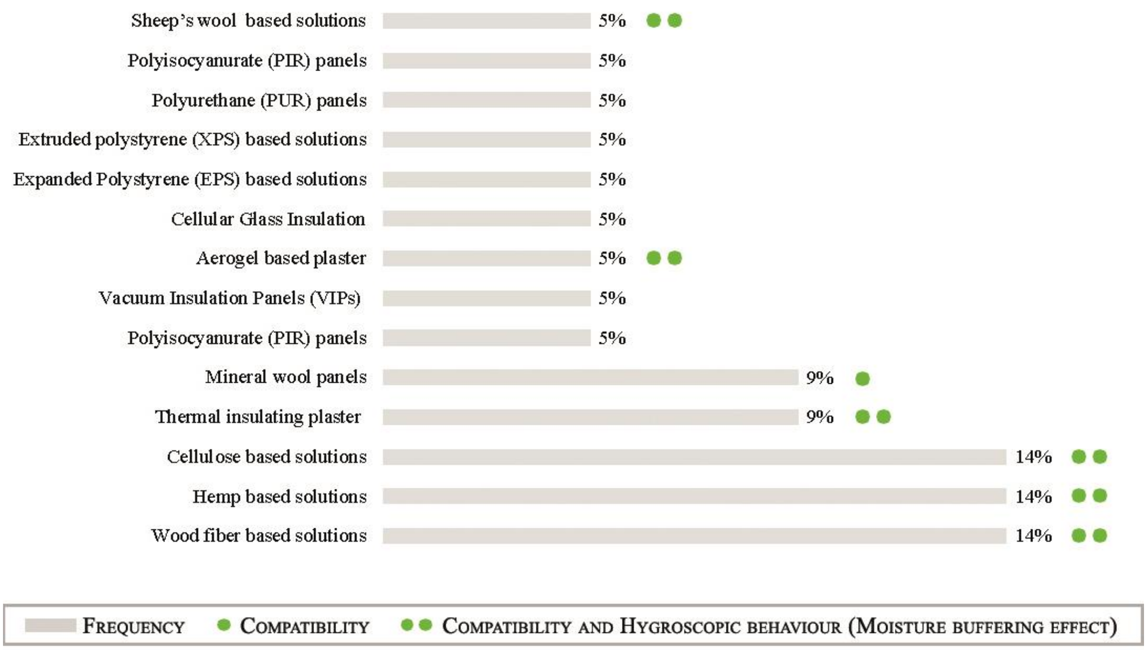

Figure 4: Floor insulation solutions in historic buildings (frequency in literature, compatibility and moisture buffering effect).

3.4. Windows

The main interventions found for windows retrofit can be grouped in two categories:

1. the ones that preserve the original windows:
   - while repairing the system and improving the component airtightness;
   - while installing a new, high performing, secondary window next to the former one, closer to the indoor environment;
2. the ones that substitute the original windows with:
   - "Smartwin historic", a solution composed by a box-window with good thermal insulating properties and a historical aspect;
   - new and better performing components.

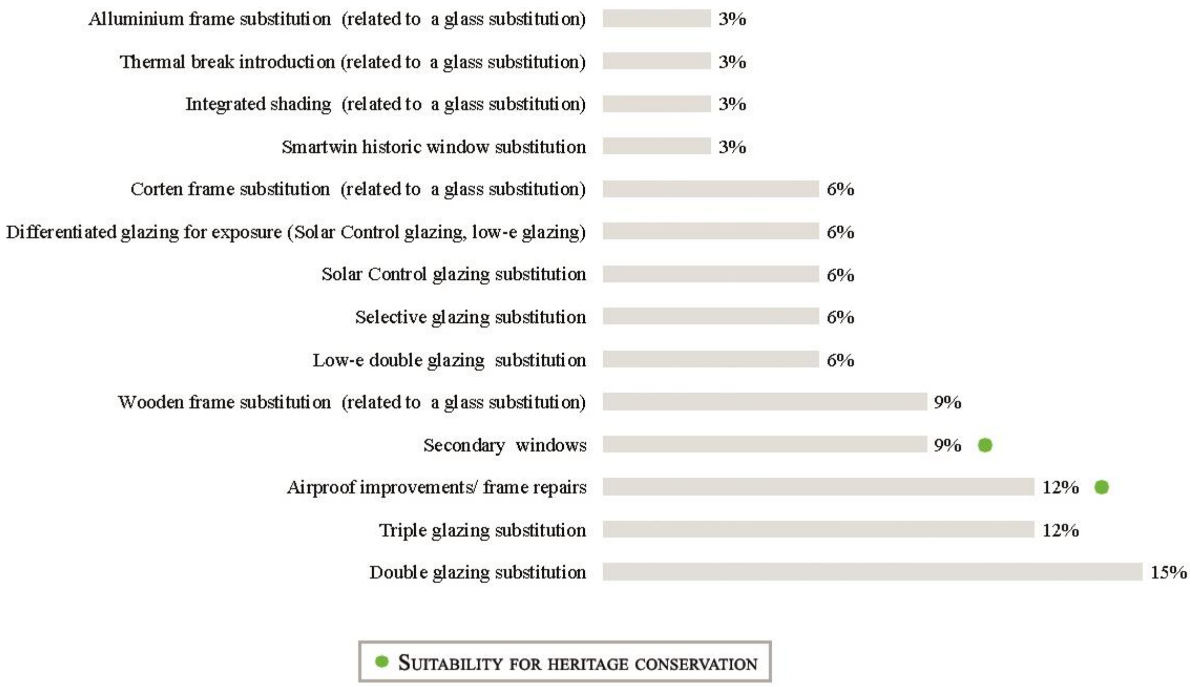

Figure 5: Windows retrofit solutions in historic buildings (frequency in literature and suitability for heritage conservation).

In literature 33 mentions have been found concerning windows retrofit solutions (n=33, in Pickles, Brocklebank and Wood., 2010; Ascione, Bianco, *et al.*, 2015; Rasmussen and Møller, 2015; Rosales Carreón, 2015; Ascione, Cheche, *et al.*, 2015; Dalla Mora *et al.*, 2015; Blumberga *et al.*, 2016; Cornaro, Puggioni and Strollo, 2016; Roberti *et al.*, 2017; Biseniece *et al.*, 2017; De Fino *et al.*, 2017; Di Ruocco, Sicignano and Sessa, 2017; Mancini *et al.*, 2017) and they are presented in Fig.5. According to the results of the review, the most common interventions are glass substitution with a double or triple glazing and repairs for improving the airtightness of the component.

3.5. Air tightness, Thermal bridges, Shading devices

Air tightness interventions are considered in Ascione, Bianco, *et al.*(2015), Rosales Carreón (2015) and Blumberga *et al.*(2016), they are generally related to windows interventions but they can also deal with doors, cracks in walls and other defects of the construction.

Two references emerged for thermal bridges reduction (Dalla Mora *et al.*, 2015; Blumberga *et al.*, 2016) but no specifications about the adopted techniques are there provided.

Shading devices are accounted to improve visual comfort conditions and reduce radiation loads in summer by Galatioto, Ciulla and Ricciu (2017), those elements can be integrated in the windows retrofit interventions as done by Biseniece *et al.*(2017) via adopting new glazing with integrated shading.

4. Energy savings via historic buildings envelope retrofitting

The results obtained from the review (De Berardinis *et al.*, 2014; Ascione, Bianco, *et al.*, 2015; Ascione, Cheche, *et al.*, 2015; Cornaro, Puggioni and Strollo, 2016; Cirami *et al.*, 2017; Di Ruocco, Sicignano and Sessa, 2017; Roberti *et al.*, 2017) in terms of energy savings via walls interventions (n=15), windows retrofits (n=9) and combinations of several solutions (n=9) are summarised in Fig.6.

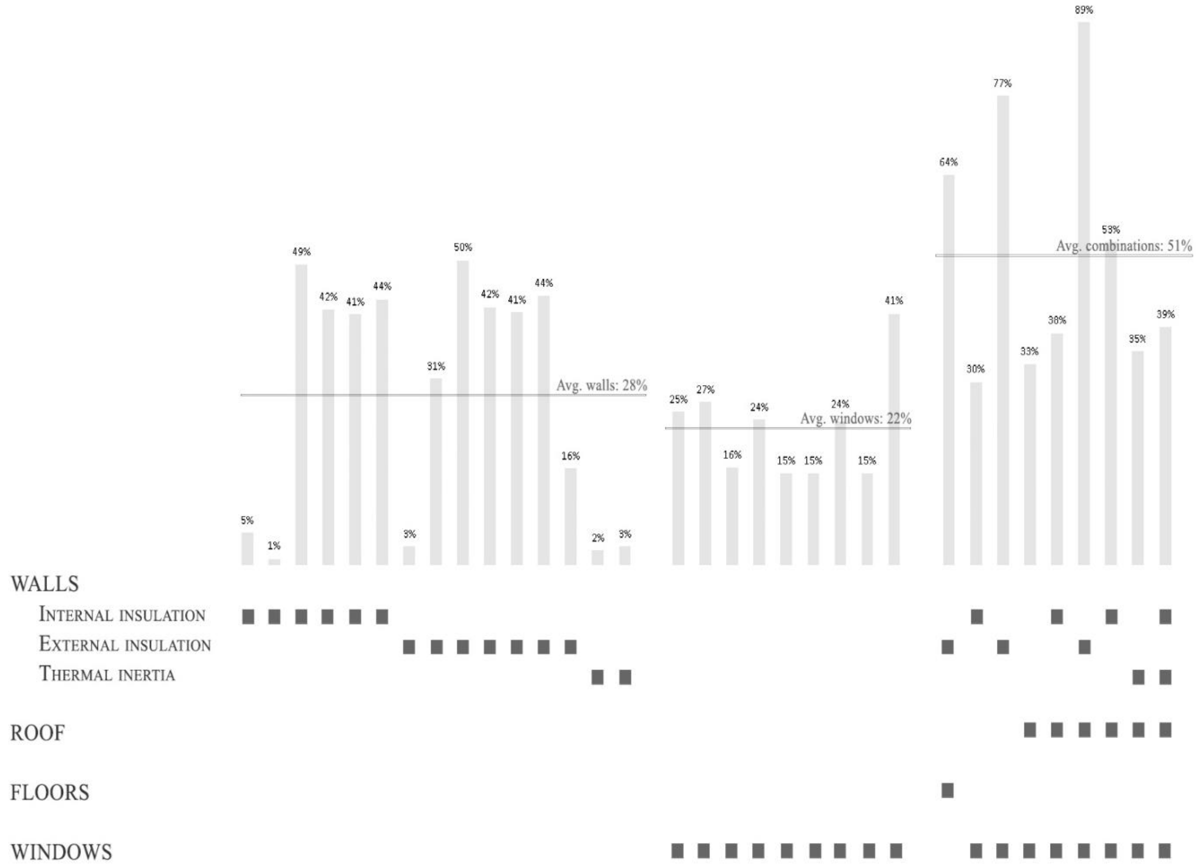

Figure 6: Annual energy savings via walls, windows and combined interventions.

It emerges that envelope energy retrofits lead to achieve significant energy consumption reductions, especially when combinations of several interventions are adopted. Through walls, windows and combined interventions it is possible to achieve average savings of 28%, 22% and 51%, respectively.

5. Conclusions

It is possible to conclude that there is a high variety of solutions that can be adopted for energy retrofits of historic envelopes. Among them, EPS based solutions, mineral wool panels, thermal insulating renders and plasters are the most common materials for walls interventions. The last three solutions have high water vapour permeability but only renders and plasters can be accounted as materials that can contribute to the moisture buffering natural behaviour of historic vertical components. For roofs, the most discussed solutions are mineral wool and cellulose, they both have good vapour permeability and the second also have a positive hygroscopic behaviour. As long as floors are concerned, the highest number of mentions is found for cellulose, hemp and wood fibers based materials and they are all very suitable for being adopted. Regarding windows, it is very common to find replacement of glasses and frames in literature but such solutions are not respectful of the principle of authenticity and they strongly alter buildings original appearance, therefore airproof improvements, repairs and the addition of secondary windows have to be considered as more suitable solutions.

All in all, results show that the interventions provided in literature are able to lead to significant energy savings, 22% to 51% on average. On the other hand, it is possible to state that only part of the proposed interventions appears compatible with historic materials and respectful of the principle of authenticity. Moreover, the adequacy of the solutions for the different European climates should be better analysed and understood. Therefore, future researches are considered to be necessary in order to define the energy savings obtainable with compatible envelope retrofit solutions for well-known samples of Historic buildings and specific climate types.

Acknowledgements

The authors thank the financial support provided by FCT and CONSTRUCT and the institutions hosting the research: FEUP and LNEC (Project PRESERVE – Preservation of renders of built cultural heritage).

References

Andra Blumberga, Dagnija Blumberga, E. K., Agris and Kamenders , Kristaps Kass , Reinis Purvins, G. Z. (2016) 'Robust Internal Thermal Insulation of Historic Buildings - Report on historical building types and combinations of structural solutions', p. 688. doi: 10.1002/ejoc.201200111.

Ascione, F., Cheche, N., Masi, R., Minichiello, F. and Vanoli, G. (2015). Design the refurbishment of historic buildings with the cost-optimal methodology: The case study of a XV century Italian building. *Energy and Buildings*, 99, pp.162-176. doi: 10.1016/j.enbuild.2015.04.027.

Ascione, F., Bianco, N., De Masi, R., de'Rossi, F. and Vanoli, G. (2015). Energy retrofit of an educational building in the ancient center of Benevento. Feasibility study of energy savings and respect of the historical value. *Energy and Buildings*, 95, pp.172-183. doi: 10.1016/j.enbuild.2014.10.072.

Ascione, F., De Rossi, F. and Vanoli, G. P. (2011) 'Energy retrofit of historical buildings: Theoretical and experimental investigations for the modelling of reliable performance scenarios', *Energy and Buildings*, 43(8), pp. 1925–1936. doi: 10.1016/j.enbuild.2011.03.040.

Baggio, M., Tinterri, C., Mora, T., Righi, A., Peron, F. and Romagnoni, P. (2017). Sustainability of a Historical Building Renovation Design through the Application of LEED® Rating System. *Energy Procedia*, 113, pp.382-389. doi: 10.1016/j.egypro.2017.04.017.

Biseniece, E., Žogla, G., Kamenders, A., Purviņš, R., Kašs, K., Vanaga, R. and Blumberga, A. (2017). Thermal performance of internally insulated historic brick building in cold climate: A long term case study. *Energy and Buildings*, 152, pp.577-586. doi: 10.1016/j.enbuild.2017.07.082.

Brandt, M. T. (2017) 'Buildings and stories: Mindset, climate change and mid-century modern', *Journal of Architectural Conservation*, 23(1–2), pp. 36–46. doi: 10.1080/13556207.2017.1327195.

Cellura, M., Ciulla, G., Guarino, F., and Longo, S.. (2017) 'Redesign of a Rural Building in a Heritage Site in Italy: Towards the Net Zero Energy Target', *Buildings*, 7(3), p. 68. doi: 10.3390/buildings7030068.

Cirami, S., Evola, G., Gagliano, A. and Margani, G. (2017). Thermal and Economic Analysis of Renovation Strategies for a Historic Building in Mediterranean Area. *Buildings*, 7(4), p.60. doi: 10.3390/buildings7030060.

Cornaro, C., Puggioni, V. A. and Strollo, R. M. (2016) 'Dynamic simulation and on-site measurements for energy retrofit of complex historic buildings: Villa Mondragone case study', *Journal of Building Engineering*. Elsevier, 6, pp. 17–28. doi: 10.1016/j.jobe.2016.02.001.

Dalla Mora, T., Cappelletti, F., Peron, F., Romagnoni, P. and Bauman, F. (2015). Retrofit of an Historical Building toward NZEB. *Energy Procedia*, 78, pp.1359-1364. doi: 10.1016/j.egypro.2015.11.154.

De Berardinis, P., Rotilio, M., Marchionni, C. and Friedman, A. (2014). Improving the energy-efficiency of historic masonry buildings. A case study: A minor centre in the Abruzzo region, Italy. *Energy and Buildings*, 80, pp.415-423. doi: 10.1016/j.enbuild.2014.05.047.

De Fino, M., Scioti, A., Cantatore, E. and Fatiguso, F. (2017). Methodological framework for assessment of energy behavior of historic towns in Mediterranean climate. *Energy and Buildings*, 144, pp.87-103. doi: 10.1016/j.enbuild.2017.03.029.

Galatioto, A., Ciulla, G. and Ricciu, R. (2017) 'An overview of energy retrofit actions feasibility on Italian historical buildings', *Energy*. Elsevier Ltd, 137, pp. 991–1000. doi: 10.1016/j.energy.2016.12.103.

Mancini, F., Clemente, C., Carbonara, E., & Fraioli, S. (2017). Energy and environmental retrofitting of the university building of Orthopaedic and Traumatological Clinic within Sapienza Città Universitaria. *Energy Procedia*, 126, pp.195-202

Martínez-Molina, A., Tort-Ausina, I., Cho, S. and Vivancos, J. (2016). Energy efficiency and thermal comfort in historic buildings: A review. *Renewable and Sustainable Energy Reviews*, 61, pp.70-85. doi: 10.1016/j.rser.2016.03.018.

Mosoarca, M., Keller, A., Petrus, C. and Racolta, A. (2017). Failure analysis of historical buildings due to climate change. *Engineering Failure Analysis*, 82, pp.666-680. doi: 10.1016/j.engfailanal.2017.06.013.

Nik, V., Mata, E., Sasic Kalagasidis, A. and Scartezzini, J. (2016). Effective and robust energy retrofitting measures for future climatic conditions—Reduced heating demand of Swedish households. *Energy and Buildings*, 121, pp.176-187. doi: 10.1016/j.enbuild.2016.03.044.

Nik, V. M. and Arfvidsson, J. (2017) 'Using Typical and Extreme Weather Files for Impact Assessment of Climate Change on Buildings', *Energy Procedia*. Elsevier B.V., 132, pp. 616–621. doi: 10.1016/j.egypro.2017.09.686.

Pickles, D., Brocklebank, I. and Wood., C. (2012) 'Energy Efficiency and Historic Buildings: Application of Part L of the Building Regulations to historic and traditional constructed buildings, pp. 1–72. doi: 978-1-4098-3413-7.

Pickles, D., Brocklebank, I. and Wood., C. (2012) 'Energy Efficiency and Historic Buildings: Application of Part L of the Building Regulations to historic and traditional constructed buildings. Insulating pitched roofs at ceiling level-cold roofs, pp. 1–72. doi: 978-1-4098-3413-7.

Pickles, D., Brocklebank, I. and Wood., C. (2012) 'Energy Efficiency and Historic Buildings: Application of Part L of the Building Regulations to historic and traditional constructed buildings. Insulation of suspended timber floors, pp. 1–72. doi: 978-1-4098-3413-7.

Rasmussen, T. V. and Møller, E. B. (2015) 'Extensive Renovation of Heritage Buildings - Reduced Energy Consump- tion and CO 2 Emissions', pp. 58–67.

Roberti, F., Oberegger, U., Lucchi, E. and Troi, A. (2017). Energy retrofit and conservation of a historic building using multi-objective optimization and an analytic hierarchy process. *Energy and Buildings*, 138, pp.1-10. doi: 10.1016/j.enbuild.2016.12.028.

Rosales Carreón, J. (2015) 'Review on techniques, tools and best practices for energy efficient retrofitting of heritage buildings'. Available at: https://scholar.google.co.uk/scholar?hl=en&as_sdt=0%2C5&q=Review+on+techniques%2C+tools+and+best+practices+for+energy+efficient+retrofitting+of+heritage+buildings&btnG=.

Di Ruocco, G., Sicignano, C. and Sessa, A. (2017) 'Integrated Methodologies Energy Efficiency of Historic Buildings', *Procedia Engineering*. The Author(s), 180, pp. 1653–1663. doi: 10.1016/j.proeng.2017.04.328.