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Are the Best Available Technologies the only viable for energy interventions in historical buildings?

Rappresentano le BAT le sole tecnologie applicabili per interventi energetici negli edifici storici?

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SUMMARY

Worth aged buildings represent among the existing buildings a special case when it comes to their energy refurbishment. Current available technologies for building components, characterized by high level of thermal performances, unfortunately, are also characterized, not rarely, by limited compatibility with the architectural integrity of the building. In other words, the so-called Best Available Technologies that are effectively adopted to optimize the energy performances of buildings, in the case of aged buildings to which a certain artistic, historic and/or architectural merit is recognized (heritage houses) could, actually, determine such kind of conflicts and therefore leading to the selection of "non-invasive" but less performing building and plant elements.

To check the effectiveness of these less performing technologies, we investigated the energy performance of two different refurbishment configurations of the building envelope of a heritage house: a "best available technology" scenario, in which interventions assumed consist of using the best available technology for energy saving; and an "allowed best technology" scenario, in which interventions assumed consist of using technologies that, although not the best available, are anyway "allowable" according to the cultural heritage preservation requisites and rules. A cost-based comparison between these configurations of the building envelope was also carried out.

Results of this comparative analysis are reported in this paper.

RIASSUNTO

Gli edifici di pregio rappresentano, tra quelli esistenti, un caso speciale quando ci si confronta con la riqualificazione energetica. Le tecnologie attualmente disponibili per i componenti edilizi, caratterizzate da un'elevata prestazione termica, sfortunatamente sono anche, non raramente, affette da una limitata compatibilità con l'integrità architettonica dell'edificio. In altre parole, le cosiddette migliori tecnologie disponibili (BAT) che sono efficacemente adottate per ottimizzare le prestazioni energetiche degli edifici, nel caso degli edifici storici, ai quali è riconosciuto un certo valore artistico, storico e/o architettonico (edifici di pregio o del patrimonio culturale), potrebbero in realtà tale tipo di conflitti e quindi condurre alla scelta di elementi di involucro e di impianto "non invasivi" ma meno performanti. Per controllare 'efficacia di queste meno performanti tecnologie, abbiamo investigato la prestazione energetica di due diverse configurazioni di riqualificazione energetica dell'involucro edilizio di un edificio storico: uno scenario "migliore tecnologia disponibile", in cui gli interventi ipotizzati consistono nell'impiego della migliore tecnologia disponibile per il risparmio energetico; e uno scenario "migliore tecnologia adottabile" , in cui gli interventi ipotizzati consistono nell'impiego di soluzioni tecnologiche che, sebbene non le migliori disponibili, sono comunque certamente adottabili secondo gli standard ed i regolamenti per la conservazione del patrimonio culturale degli edifici. E' stato altresì condotto un confronto economico delle due configurazioni dell'involucro edilizio.

I risultati di questa analisi comparativa sono riportati nell'articolo.

Key words: energy efficiency, preservation, energy refurbishment

Parole chiave: efficienza energetica, conservazione, interventi di riqualificazione energetica

1. INTRODUCTION

The energy consumption for space heating and cooling of buildings, as it is well known, represents a significant part of the energy balance of a country (Cédric, 2006; Kohler and Hassler, 2012; International Energy Agency, 2012a, 2012b). To reach the ambitious EU goals of reducing the buildings energy consumption, Member States are called to adopt more incisive and binding measures for the energy rehabilitation of the building stock.

Apart from this general concern, countries with noteworthy cultural heritage are called to pay particular attention to energy consumption of historical buildings, since the energy demand from such buildings represents a not negligible part of the whole building stock demand. In Italy, for example, approximately 70% of buildings (data based on ISTAT Census 2001) were built before the emanation of the first law (released in 1976) establishing limits for the energy consumption in the building sector; as that, it is likely that a certain part of this large amount of buildings could be classified as heritage houses, despite a specific statistical analysis is not currently available. As matter of fact, several buildings in Italy are under the protection of the Superintendence of Artistic and Cultural Heritage that intervenes when modifications of such buildings are proposed.

The energy consumption of historical buildings in EU is currently estimated at more than 200 kWh/m^2 year [1]; despite such a high energy use, indoor conditions provided to occupants are often scarce and generally tolerated only because of the cultural and environmental worthiness of such constructions.

While this issue seems to only marginally interest discontinuously occupied historical buildings (such as museums, for example), it is particularly significant for historical buildings used for residential, working and commercial purposes, representing, actually, the greatest relevant part of the historic buildings stock.

These continuously occupied buildings are supposed to be generally more energy consumer (Fabbri et al., 2012) since they are called to provide good quality indoor conditions (La Gennusa et al., 2005; La Gennusa et al., 2008). In fact, people living and working in this kind of buildings do require suitable indoor conditions in terms of thermal, acoustic, visual and IAQ performances (Franzitta, et al., 2010) comparable to those of modern buildings.

Despite such a high energy consumption, however the EU Directive 2002/91 on the energy performance of buildings (European Parliament and Council, 2002), expressly excludes *buildings and monuments officially protected as part of a designated environment or because of their special architectural or historic merit,* from both the procedure for energy certification and possible interventions of energy retrofitting, when *compliance with the requirements would unacceptably alter their character or appearance* (article 4, paragraph 3). That is, for this kind of buildings Member States are allowed not take the necessary measures to meet the minimum energy performance requirements. Such a position is substantially confirmed in the recent EU directive 2010/31/EC (European Parliament and Council, 2010) in which the possibility of the energy rehabilitation is extended also to buildings that may be defined as historical, but as long as their historical identity and quality is not compromised by invasive interventions (article 4, paragraph 2, decreto-legge 4 giugno 2013, n. 63).

In addition to the regulations on the buildings energy performance, in Italy historical buildings are also disciplined and preserved by regulations on cultural and landscape heritage (Italian Government, 2004) that define possible interventions and methodologies for their conservation.

The assessment of the compatibility of a new element addition to a historic building is an issue that has been largely debated in the field of architectural conservation (Yuceer and Ipekoglu, 2012).

In the case that an energy retrofit of a heritage house should occur, for example at owner's request, one would be pushed towards the adoption of the "best available technologies" (BAT) on the base of their performances, but unfortunately these, not rarely, are characterized by a limited compatibility with the architectural integrity of the building: at this regard, it is emblematic, for example, the case of solar collectors aimed at producing hot water or electric power which could be hardly used in a heritage house. In such a case, it may result therefore necessary the selection of "non-invasive" but less performing building and plant elements whose effectiveness should however be checked both from an energy and economic point of view.

With the aim of investigating the potential in terms of energy performance improvement, of these "non-invasive" solutions for the energy retrofit, compared to the one of the "invasive" ones, we selected as an emblematic case a building belonging to the category of heritage houses and compared two different energy rehabilitation scenarios: a "best available technology" scenario, in which interventions assumed consist of using the best available technology for energy saving; and an "allowed best technology" (ABT) scenario, in which interventions assumed consist of using technologies that, although not the best available, are anyway "allowable" according to the cultural heritage preservation

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requisites and rules. A cost-based comparison between these two configurations of the building envelope has been also carried out.

2. THE SELECTED BUILDING

In this section, after a brief description of the building under consideration, an energy performance analysis of the case-study in its current state is reported. It represents the baseline scenario which the two hypothesized scenarios are compared to.

2.1. Description and characteristics

For the study presented here, we have selected a historical building located in the historic center of Ragusa, in the South coast of Sicily, that is named "Palazzo Battaglia". The building belongs to a climatic zone characterized by 1324 Degree Days (DD) and by a design outdoor temperature of 0,0 °C; the building is situated at a height of 502 m over the sea level.

The construction with a quadrangular layout dates back to XVIII century. The palace was seriously damaged during an earthquake happened in 1693 and reconstructed in 1727, in Baroque style. It consists of three floors plus one located between the ground and the first floor, with a number of apartments of 3, 2 and 2, respectively. Figure 1 reports a building view from the outside along with some details of the façades. The entire structure is composed of *tufo* stones which are combined with mortar. The horizontal parts of the structure of both the ground floor and the floor, positioned between the ground floor and the first one, stand on barrel vault and cross vaults made of limestone elements, support stones and lime subfloor, on which the stone flooring stands. In the first floor, the horizontal structures are in double wood warping with the vault made of canes and gypsum with support of stone and gypsum; the same typology has been used for the horizontal part of the attic floor, where, anyway, at the end of fifties a deep structural intervention generated a hollow space made of wood and Sicilian pan tiles.

This building has been selected because it represents a typical example of the building stock of this part of Sicily. Also the interventions that make interesting the building during the time, can be considered as typical of the story of such kind of buildings.

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Figure 1 – Main perspective and details of some façades of the historical building selected for the application

2.2. Energy performance

The assessment of the energy performance of our case-study in its current state, which represents the baseline scenario, has been carried out using one of the national available software based on the Italian standard UNI-TS 11300 (UNI, 2008), that is the Italian standard for the evaluation of energy demand for space heating and cooling of buildings, a transposition of the international standard ISO 13790 (ISO, 2008).

The heating system has been omitted in the simulation and only the thermo-physical characteristics of the building envelope (opaque and glazed elements) have been considered. Hence, the primary energy demand has been calculated assuming the presence of electric space heating devices (Milone et al., 2009; Milone et al., 2008). Figure 2 and Figure 3 illustrate by means of synthetic technical sheets opaque and glazed elements present in the baseline scenario, respectively.

The energy audit has been carried out for each floor and for single thermal zones separately, since three homogenous thermal zones have been identified. As that, from the energy point of view the building has been separately verified for each different thermal zone.

The first, second and third floors are characterized by a value of the Surface/Volume (S/V) ratio of 0.75, 0.41, and 0.53, respectively.

It is also important to note that the basement is not included in the energy evaluation of the building, being not used for residential purposes; as that, this volume is here intended as a buffer thermal zone between the first floor of the building and the ground.

In Table I the parameter EP represents the energy demand of the building reported in terms of the primary energy required to generate the actual amount of energy required for the building climatization (kWh/m^2/y). $EPi_{,lim}$ is the law limit of this parameter for the considered climatic zone and EP_i is the so called “winter energy performance” index, that is the specific primary energy taking into account the only winter climatization purposes.

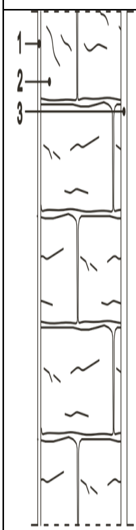
<table>
<tr><td colspan="10">Stratigraphy</td></tr>
<tr><td rowspan="8"></td><td colspan="9">Indoor liminar coefficient including convective and radiative heat exchange 7,69 (W/mK)</td></tr>
<tr><td rowspan="2">1</td><td rowspan="2">Lime-sand gypsum plaster λ=0.79 W/mK ρ=1.400 Kg/m³</td><td>Thickness (mm)</td><td colspan="6">20</td></tr>
<tr><td>R (m²K/W)</td><td colspan="6">0.025</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">Tufo λ=0.63 W/mK ρ=1.500 Kg/m³</td><td>Thickness (mm)</td><td>460</td><td>560</td><td>660</td><td>790</td><td>860</td><td>980</td></tr>
<tr><td>R (m²K/W)</td><td>0.73</td><td>0.88</td><td>1.04</td><td>1.25</td><td>1.36</td><td>1.55</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">Lime plaster λ=0.90 W/mK ρ=1.800 Kg/m³</td><td>Thickness (mm)</td><td colspan="6">20</td></tr>
<tr><td>R (m²K/W)</td><td colspan="6">0.022</td></tr>
<tr><td colspan="9">Outdoor liminar coefficient including convective and radiative heat exchange 25 (W/mK)</td></tr>
<tr><td colspan="4">Total Thickness (mm)</td><td>500</td><td>600</td><td>700</td><td>830</td><td>900</td><td>1000</td></tr>
<tr><td colspan="4">Thermal resistance U (m²K/W)</td><td>0.95</td><td>1.11</td><td>1.26</td><td>1.47</td><td>1.586</td><td>1.776</td></tr>
<tr><td colspan="4">Trasmittance U (W/m²K)</td><td>1.052</td><td>0.901</td><td>0.788</td><td>0.678</td><td>0.631</td><td>0.563</td></tr>
<tr><td colspan="4">Frontal Mass (Kg/m²)</td><td>690</td><td>840</td><td>990</td><td>1185</td><td>1290</td><td>1470</td></tr>
</table>

Figure 2 – Vertical opaque elements in the current condition

3. ENERGY REHABILITATION SCENARIOS

In the following it is provided a description of interventions on opaque and glazed elements of the building envelope assumed in the present work in both energy rehabilitation scenarios: “Best Available Technology” scenario (BAT) and “Allowed Best technology Scenario” (ABT).

3.1. Best Available Technology scenario

The concept of Best Available Techniques (BAT) is a well-established definition which was firstly presented in the IPPC Directive 96/61/EC (European Council, 1996).

Ideally separating the building from its historical context, all the best current technologies for the energy rehabilitation of the building envelope could be considered as allowable.

For example, a thermal barrier coating to be implemented on the vertical opaque surfaces has been here chosen. The hypothesized building component is made of EPS (acronym of “expanded synthesized polystyrene”), that is characterized by a low thermal conductivity. In the application we have chosen a layer made of this material,

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whose thickness is 40 mm, with a thermal resistance, R, of 1,29 m^2K/W (as indicated in Figure 4).

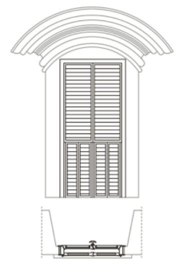
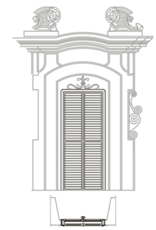
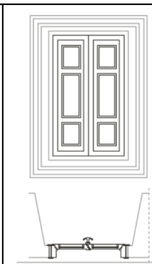
	Typologies of windows			
				
Glass area A_g (m^2)	1.692	1.84	2.63	0.93
Windows Frame Area A_f (m^2)	0.508	0.58	0.687	0.25
Total Area A_W (m^2)	2.2	2.42	3.31	1.15
Glass typology	Single 5 mm			
Glass transmittance U_g (W/m^2K)	5.713			
Materials used in the windows frame	wood			
Transmittance of windows frame U_f (W/m^2K)	2.003			
Types of rolling shutter	wood			
Permeability level	Low	High	High	Low
Added Thermal resistance (W/m^2K)	0.30	0.14	0.14	0.30
Total trasmittance U_w (W/m^2K)	4.856	4.824	5.019	4.909
Trasmittance including the rolling shutter U_{wcoff} (W/m^2K)	3.129	3.657	3.776	3.155

Figure 3 – Glazed elements in the current condition

Table I – Energy performance of various levels in the current state (baseline scenario)

Floor			1	2	3
Energy demand (winter and summer)		kWh Y	15800,7	35482,8	19026,9
Winter Energy performance index	EPi	kWh/m^2 Y	31,72	36,92	48,87
Primary energy limit index (winter season)	$EP_{i, lim}$		55,27	33,46	41,16
Energy Class			B	B	C

Another intervention has been implemented on glazed elements. More specifically, we have chosen a window frame made of aluminium with thermal cutting. The glazed element is equipped with a single-chamber window filled with argon showing a glass thickness of 4 mm and a plastic spacer; the glass guarantees a very low transmittance of 1.305 W/m^{2}K (as indicated in Figure 5).

Figure 4 and Figure 5 illustrate the schematic technical sheets concerning opaque and glazed elements used for energy retrofit, respectively.

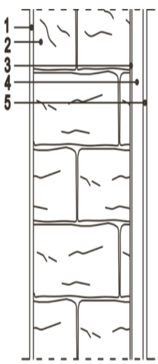
Stratigraphy									
	Indoor liminar coefficient including convective and radiative heat exchange 7,69(W/mK)								
	1	Lime-sand gypsum plaster λ=0.79 W/mK ρ=1.400 Kg/m^3	Thickness (mm)	20					
			R (m^{2}K/W)	0.025					
	2	Tufo λ=0.63 W/mK ρ=1.500 Kg/m^3	Thickness (mm)	460	560	660	790	860	980
			R (m^{2}K/W)	0.73	0.88	1.04	1.25	1.36	1.55
	3	Cement lime mortar λ=0.90 W/mK ρ=1.800 Kg/m^3	Thickness (mm)	10					
			R (m^{2}K/W)	0.011					
	4	Insulating Layer in EPS λ=0.031 W/mK ρ=20 Kg/m^3	Thickness (mm)	40					
			R (m^{2}K/W)	1.29					
	5	Platic plaster thermal coating λ=0.33 W/mK ρ=1.300 Kg/m^3	Thickness (mm)	20					
			R (m^{2}K/W)	0.061					
	Outdoor liminar coefficient including convective and radiative heat exchange 25 (W/mK)								
Total Thicknes (mm)				550	650	750	880	950	1070
Thermal resistance U (m^{2}K/W)				2.291	2.45	2.608	2.815	2.926	3.116
Trasmittance U (W/m^{2}K)				0.437	0.408	0.383	0.355	0.342	0.321
Frontal Mass (Kg/m^2)				709	859	1009	1204	1309	1489

Figure 4 – Vertical opaque elements in the BAT scenario

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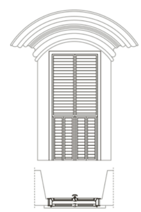
	Typologies of windows			
				
Glass area A_g (m^2)	1.69	1.62	2.37	0.82
Windows Frame Area A_f (m^2)	0.69	0.79	0.94	0.32
Total Area A_W (m^2)	2.20	2.42	3.31	1.15
Glass typology	Double 4 Argon 4			
Glass transmittance U_g (W/m^2K)	1.305			
Materials used in the windows frame	Aluminium whith thermal cutting			
Transmittance of windows frame U_f (W/m^2K)	0.225			
Types of rolling shutter	wood			
Permeability level	Low	High	High	Low
Added Thermal resistance (W/m^2K)	0.30	0.14	0.14	0.30
Total trasmittance U_w (W/m^2K)	1.106	1.091	1.2	1.106
Trasmittance including the rolling shutter U_{wcoff} (W/m^2K)	0.94	1.004	1.029	0.94

Figure 5 – Vertical glazed elements in the BAT scenario

3.2. Allowed Best Technology scenario

In this scenario, where the building is properly reported back into its own historical context, we investigated the most suitable interventions to be implemented, which are also allowed by preservation standards, set in the Italian Legislative Decree 42/2004 (Italian Government, 2004).

As regards interventions on opaque surfaces, we had to exclude the possibility to realize a thermal barrier coating as in the previously described scenario; both the thickness of the material to be applied and the relative finishing plaster would have, in fact, irreversibly modified the aesthetic worthiness of the building, mainly because plasters or decorations would then have necessarily been removed and elements present in the façade consequently flattened.

The plaster adopted in the simulation is an anhydrous mix of hydraulic lime, kaolin, expanded perlite, cork flour, natural fibers as reinforcement, able to create an alveolar structure providing a very low thermal conductivity, estimated at 0,056 W/m K with a rather low vapor resistance, a thermal resistance, R, of 0,625 m^2K/W, and a thickness of 35 mm.

Figure 6 contains the synthetic technical sheets concerning opaque elements used for energy retrofit.

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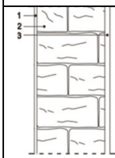
<table>
<tr><td colspan="10">Stratigraphy</td></tr>
<tr><td rowspan="8"></td><td colspan="9">Indoor liminar coefficient including convective and radiative heat exchange 7,69(W/mK)</td></tr>
<tr><td rowspan="2">1</td><td rowspan="2">Lime-sand gypsum plaster λ=0.79 W/mK ρ=1.400 Kg/m^3</td><td>Thickness (mm)</td><td colspan="6">20</td></tr>
<tr><td>R (m^2K/W)</td><td colspan="6">0.025</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">Tufo λ=0.63 W/mK ρ=1.500 Kg/m^3</td><td>Thickness (mm)</td><td>460</td><td>560</td><td>660</td><td>790</td><td>860</td><td>980</td></tr>
<tr><td>R (m^2K/W)</td><td>0.73</td><td>0.88</td><td>1.04</td><td>1.25</td><td>1.36</td><td>1.55</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">Lime plaster λ=0.056 W/mK ρ=540 Kg/m^3</td><td>Thickness (mm)</td><td colspan="6">35</td></tr>
<tr><td>R (m^2K/W)</td><td colspan="6">0.625</td></tr>
<tr><td colspan="9">Outdoor liminar coefficient including convective and radiative heat exchange 25 (W/mK)</td></tr>
<tr><td colspan="4">Total Thickness (mm)</td><td>515</td><td>615</td><td>715</td><td>845</td><td>915</td><td>1015</td></tr>
<tr><td colspan="4">Thermal resistance U (m^2K/W)</td><td>1.56</td><td>1.72</td><td>1.88</td><td>2.08</td><td>2.2</td><td>2.39</td></tr>
<tr><td colspan="4">Trasmittance U (W/m^2K)</td><td>0.64</td><td>0.58</td><td>0.53</td><td>0.479</td><td>0.455</td><td>0.418</td></tr>
<tr><td colspan="4">Frontal Mass (Kg/m^2)</td><td>690</td><td>840</td><td>990</td><td>1185</td><td>1290</td><td>1470</td></tr>
</table>

Figure 6 – Vertical opaque elements in the ABT scenario

As regards glazed elements, we assumed the same intervention adopted in the “Best Available Technology” scenario, but this time wood rather than aluminum with "thermal cutting " was the selected material, because the last one would not be suitable from an aesthetical point of view; in more detail, we selected a wood frame having a thickness of 100 mm. Wood-made rolling shutters have been assumed also in this scenario, that leads to a percentage reduction of the total transmittance of the glazed surface ranging from 8% to 19%, depending on the type of considered glazed surface an window frame.

Figure 7 contains the synthetic technical sheets concerning glazed elements used for energy retrofit.

	Typologies of windows			
				
Glass area A_g (m^2)	1.509	1.627	2.376	0.826
Windows Frame Area A_f (m^2)	0.691	0.793	0.942	0.325
Total Area A_W (m^2)	2.2	2.42	3.318	1.152
Glass typology	Double 4 Argon 4			
Glass transmittance U_g (W/m^2K)	1.305			
Materials used in the windows frame	Wood			
Transmittance of windows frame U_f (W/m^2K)	1.474			
Types of rolling shutter	Wood			
Permeability level	Low	High	High	Low
Added Thermal resistance (W/m^2K)	0.30	0.14	0.14	0.30
Total trasmittance U_w (W/m^2K)	1.563	1.577	1.631	1.516
Trasmittance including the rolling shutter U_{wcoff} (W/m^2K)	1.263	1.406	1.449	1.232

Figure 7 – Vertical glazed elements in the ABT scenario

The interventions hypothesized on opaque vertical and glazed elements contribute to make the building more energy efficient, but clearly at a different level. In the following, the effectiveness of technologies allowed by preservation standards against the one of best available technologies is discussed.

4. DISCUSSION ABOUT THE ADOPTED SCENARIOS

The two above described energy retrofit scenarios are here compared. Other than the energy issues, the discussion concerning results will be conducted also on the basis of the cost comparison.

The comparison among the scenarios, previously discussed, outlines that the first group of interventions, that is those hypothesized in the BAT scenario, therefore, considered as the possible best one, allows to achieve the highest level of overall energy efficiency in each floor of the building. In fact, referring to Figure 8, the yearly overall energy demand in the BAT scenario, taking into account both winter and summer requirements, is lower that one of the baseline scenario for each floor. Also the energy demand pertinent to the “allowable” scenario (ABT) shows values lower than those of the baseline situation.

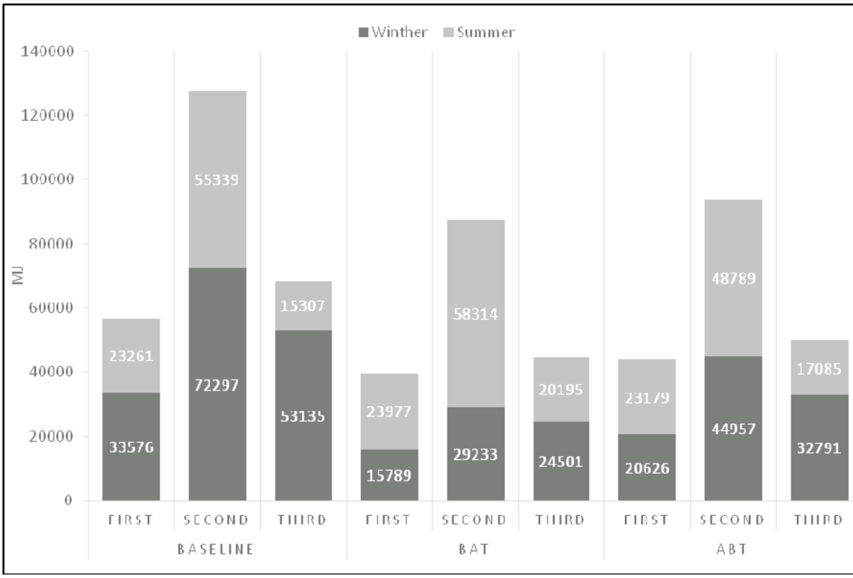


Figure 8 – Thermal energy need on a yearly base of the three floors

More in details, the application of the current Italian scheme for the energy certification of buildings, would indicate that the primary energy indicators for heating purposes (that is the primary energy yearly required for heating one square meter of the building) of baseline case are always higher than those of BAT and ABT ones (Table II).

Table II – A comparison of the three scenarios based on the EPi and energy class

	Baseline		**ABT**		**BAT**	
	Ep_i [kWh/m^2 year]	*energy class*	Ep_i [kWh/m^2 year]	*energy class*	Ep_i [kWh/m^2 year]	*energy class*
first floor	31,72	*B*	19,49	*A*	14,92	*A*
second floor	36,92	*D*	22,96	*B*	14,93	*A*
third floor	48,87	*D*	30,16	*B*	22,54	*B*

Specifically, the energy performance indexes Ep_i show that the application of the BAT related interventions allows the passage from class B to A in the first floor, from D to A in the second, and from D to B in the third. Even the application of actions referring to the ABT scenario produces a similar "jump" of class with the only difference of the second floor that now passes from class D (baseline) to B, instead of A. Clearly, although the adoption of BAT and ABT scenarios seems to lead to almost the same improvement in

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the energy performance of floors, the absolute values of EPi show that the BAT scenario is always better performing that the ABT one.

In conclusion, an improvement of the energy performances is achieved for all the considered floors both in the case of ABT and BAT scenario, in this way demonstrating the feasibility of the allowable technologies for heritage houses, being those not only less invasive of the BAT ones, but also maintaining a good energy performance.

Of course, it remains to check the economic suitability of the selected technological options of each scenario, in terms of costs to be borne to implement the interventions previously described. An estimation of the corresponding yearly energy saved was carried out as well.

In Table III costs to be borne to implement interventions hypothesized in BAT and ABT scenarios are indicated (DEI, 2013), along with the achievable energy savings.

Table III – Intervention costs and yearly energy savings in the BAT and ABT configurations

	BAT		ABT	
	Cost [€]	Energy saving [kWh/Y]	Cost [€]	Energy saving [kWh/Y]
Wall	44770	11817	73224	10810
Windows	13364	7086	27984	7381
Total	58134	22474	101208	18191

Quite interesting lessons can be learnt from these economic results. As it is possible to note, in fact, the economic comparison of BAT and ABT scenarios shows the apparently surprising result that, in case of the introduction of best available technologies (BAT), the total intervention cost (58134 €) is less than in the case of interventions referred to technologies allowable (101208 €) for the historical building regulations (ABT). Actually, this is not so strange, when one considers the involved technologies here adopted for the rehabilitation actions. In the case of windows, in fact, the less expensive aluminum frame, that actually would represent the best technology from an energy point of view, is replaced with a wooden frame window that aesthetically better fits with the considered heritage building: it is well known that this wooden component is affected by a higher cost than the aluminum BAT one.

In the presented case, more in general, a short cost analysis of both compared options, shows that BAT action would cost 2,59 € for saving 1 kWh; on the other hand, the ABT interventions would cost 5,56 € for saving 1 kWh.

In other words, an allowable (that is possible) best technology, that better matches constraints and limits referring to the in force regulations for heritage buildings, could result in a total most expensive cost, despite the less effective energy performance in this case obtained compared to the best energy performing technologies (BAT). Of course, this conclusion cannot be assumed as a general conclusion, since more applications and case-study analysis should be performed in order of supporting this consideration. Anyway, in the present case and with reference to the building envelope, it does not sound so strange that a technology (ABT) that is in accordance with very stringent regulations could present solutions with a total cost higher than a simpler technology (BAT) that, despite assumed as the best one in the market, cannot be applied in the case of historical buildings.

Of course, this example is referred to rehabilitation actions involving only the envelope of the considered building. An intervention regarding the substitution of HVAC components could show quite different results, since in this case a best performing technology is likely affected by a higher cost than a less performing one.

In turn, in the case of a refurbishment affecting together envelope and HVAC components, the total cost of the rehabilitation would strongly depend on the extension at which both intervention are applied.

CONCLUSIONS

The present work deals with a topic often debated in countries with a large cultural heritage, that is: the energy performance of heritage buildings.

In the present study, assumed that a real heritage house's owner requires an intervention to improve its energy performance, we have questioned which technologies available for the building envelope (both for opaque and glazed surfaces) can be adopted for this buildings category. Certainly, one would firstly apply to the best energy performing available technologies (BAT). But, in case of historical buildings, one should also consider whether these technologies are consistent with the aesthetical and architectural conservation of the building. And if not, one should consider what the energy saving achievable is by using these technologies that, despite not providing the best energy performances, are however consistent with the historical and architectural conservation of the building (ABT). In other words, what is the efficacy of ABT? And how far are they from the BAT in terms of energy performance?

We tried here to answer to these questions. Through an application conducted on a typical Italian heritage building belonging to the Mediterranean area, the energy performance of selected BAT has been calculated and compared with other technologies considered as allowable from the preservation of the aesthetic features point of view. The BAT scenario comprises interventions referring to glazed and opaque surfaces, with no regards to the in force regulations for old and heritage buildings; on the contrary, the ABT scenario properly takes into account the law limits imposed by the in force regulations.

Comparisons have been proposed through the paper in terms of yearly energy demand, showing at which extent both technologically improved scenarios (BAT and ABT) determine less energy consumption for heating and refrigerating purposes, with respect to the baseline situation.

The study showed that important results in terms of reduction of the energy consumption for climatization of buildings can be achieved even when the energy retrofit of heritage buildings is carried out using modern technologies that are able to improve the building envelope performance without altering the architectural and artistic merit of such buildings.

Both technological solutions have also been compared in terms of economic performances. Taking into account the results of the energy and economic comparisons, we obtained that, in the proposed case, the ABT do require an higher investment cost than the BAT ones, whose adoption, in turn, results in a lower yearly energy saving.

In conclusion, the building technologies to be adopted in the rehabilitation or restoring of a historical building should be carefully evaluated, since in this case the best energy performing available technologies cannot be utilized, due to legislation and standard constraints. On the other hand, technologies allowable with respect to the standards regulating this kind of buildings, that are the only applicable in these cases, could result, as it has been shown in the present application, in a less effective energy performance and in a higher investment cost than the best available technologies ones.

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