RESTORATION AND CONVERSION TO RE-USE OF HISTORIC BUILDINGS INCORPORATING INCREASED ENERGY EFFICIENCY
A Case Study – the Haybarn Complex, Hilandar Monastery, Mount Athos

by

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A proper approach to restoration of historic buildings is crucial for monumental heritage protection. The objective of the paper is to define a methodology for historic buildings restoration in order to increase energy efficiency and re-usability in accordance with modern standards. The main method used in the paper is the observation of historic buildings during their restoration and exploitation, analysis and evaluation of achieved results regarding energy efficiency and energy saving, through the examples of the buildings belonging to Hilandar Monastery, Mount Athos, in Greece. Mount Athos was inscribed on the UNESCO World Heritage List for its cultural and natural values. This case study discusses the abandoned and dilapidated historic buildings of the Haybarn Complex (Stable, Mule-keepers' House, and Haybarn), the achieved results regarding the restoration of these buildings, their energy efficiency and turning into the premises for occasional stays. The research results are recommendations for increasing energy efficiency while performing the restoration of historic buildings, so that these buildings could be re-used in a new way. The most significant contribution of the paper is the practical test of energy refurbishment of these historic buildings conducted using the principles and methods of energy efficiency, in compliance with conservation requirements and authenticity of historic buildings.

Key words: *heritage conservation, energy refurbishment of historic buildings, energy saving, UNESCO cultural heritage*

Introduction

Historic buildings and their remains should be protected from further deterioration through the process of refurbishment and adaptive re-use, in accordance with modern social changes. Restoration and energy refurbishment of historic buildings breathe a new life into those buildings. The paper deals with restoration and refurbishment of abandoned buildings belonging to the Haybarn Complex of Monastery Hilandar, Mount Athos, in Greece. Not only is this restoration designed to increase energy efficiency, it also keeps the authentic look and materialization of these buildings. It was the first restoration of this type to be performed on Mount Athos.

The basic hypothesis of this paper is the statement that it is feasible to increase energy saving and energy efficiency in the process of historic buildings restoration and keep their

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authentic look and harmony with the protected localities, such as Mount Athos itself. It is achieved by applying specific construction methods.

The objective of this research is:

- to expand the knowledge about the importance of conservation, restoration, and refurbishment of historic buildings, their remains and potentials (resource),
- to conduct active exploration of localities in order to contribute to protection and conservation of cultural heritage and locality management,
- to define specific construction methods to be applied in the process of restoration of historic buildings in order to increase their energy efficiency,
- to organize the acquired knowledge in the field of energy efficiency of historic buildings,
- to provide recommendations for conservation, restoration, and refurbishment of historic buildings through energy revitalization, and
- to make research results available to açademic community.

Literature review

Restoration has been widely applied as a conservation and redevelopment method of reviving some old, dilapidated historic buildings, in terms of their architectural, functional, and economic potentials. Adaptive reuse of historic buildings implies the balance with surrounding changes and preservation of old buildings in accordance with current trend development [1].

Energy refurbishment aspect of historic buildings declared as cultural heritage is not different from other buildings. This type of refurbishment depends on specific needs and cultural heritage. The key to successful energy refurbishment of historic buildings is identification and understanding of the existing energy efficiency aspects of historic construction, so that they could be kept, saved and efficiently used together with the latest energy improvement measures. Not only do energy improvement measures imply potential energy savings, they also protect materials, features, and property of historic buildings [2].

The European regulations on reducing energy consumption relate to energy saving in the existing buildings and do not exclude historic buildings. Still, in the field of architectural heritage conservation, there is not a single international act that deals with energy and energy retrofit. The European laws do not specify minimum levels of energy performance required for historic buildings. This certainly represents a crucial issue, since historic buildings are heterogeneous and need different levels of protection and, for the time being, the regulations have not offered general suggestions about how to manage energy issues with historic buildings [3].

There are some examples of national-level regulations on historic building rehabilitation. Therefore, it can be concluded that every single country is allowed to adopt its own regulations that specify whether or not the country is obliged to meet the requirements of energy efficiency regarding the existing as well as listed historic buildings. In order to cover the gap between listed historic/historical buildings, and energy refurbishment and direct EU policies towards energy retrofit of these buildings, the national cultural heritage authorities should initiate a lobbying action in order to offer successful solutions to energy refurbishment of historic/historical buildings [4].

Since the buildings included in this study are located in Greece, *i. e.* the EU territory, and taken care of by Serbia*, this paper presents the conducted energy efficiency test of

* The monastery was restored in the 12th century by Serbian noblemen, Saint Sava and Saint Simeon, son and his father. The monastic brotherhood of Serbian origin has lived there ever since.

these historic buildings, based on the current regulations. The following regulations were applied:

– the Regulation on Energy Efficiency of Buildings [5], and
– the Regulation on Conditions, Content and Issuance of Certificates for Energy Efficiency of Buildings [6],

in accordance with the European standards and norms in this field:

– Energy Performance of Building Directive – EPBD No 2002/91/EC – Directive of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings [7], and
– Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast) [8].

With thorough planning and realization, the applied energy efficiency measures must be appropriate and without negative effects on historic character and integrity of the building itself. Ongoing monitoring of buildings, after the process of restoration, can reveal potential changes and imperfections. If so, timely interventions are to be carried out in order to prevent irreparable damage and protect the historic building. This, along with regular maintenance, can certainly ensure the long-termed preservation of our historic built environment and sustainable use of our resources [2].

Generally speaking, restoration and rehabilitation of buildings must include the following procedures in order to create energy efficient buildings of high quality [9]:

– analyses of location, orientation, and form of buildings,
– high-level thermal insulation on outer coating of buildings; thermal bridges are to be avoided,
– using heat from the sun; protection from excessive sunlight, and
– further exploitation is to include the implementation of energy efficient heating systems as well as cooling and ventilation systems along with renewable energy resources, if possible.

However, when it comes to historic buildings, implementation of these procedures is not always possible because it might affect the authentic look of these buildings. Thermal insulation as exterior wall coating must be avoided, because the loss of visual historic environment is incomparable in its significance and slight saving of energy resources is not worth such loss. Not only does this method protect the visual appearance of historic buildings, it also protects the construction system itself [10]. Heritage preservation of the building implies interior retrofitting in order to maintain all of its original exterior wall aspects [11].

Methodology

Overview of the methods implemented in this paper:

– on-site observation – qualitative research and analysis of monuments and their remains in order to define a building to be protected,
– case study as a research method (the case as a whole), used in the process of restoration and energy efficiency increase of the Haybarn Complex, Hilandar Monastery, Mount Athos,
– design and definition of construction protection criteria based on previous analyses of location conditions and chosen methods of restoration and re-use,
– restoration of historic buildings in compliance with conservation requirements: keeping authentic structural elements (façade walls, roof structure), materialisation and authentic look of buildings,
– design and restoration of a building in order to increase its energy efficiency and energy saving,

– all restoration interventions, aimed at increasing energy efficiency and re-usability, were carried out in compliance with conservation principles; it must be pointed out that the interventions are reversible,
– evaluation of the achieved results in terms of energy refurbishment, and
– checking the possibility of improving the already restored buildings by performing specific interventions in order to increase energy efficiency and energy saving.

Case study: Hilandar Monastery – the Haybarn Complex

Specific characteristics of the site

For more than a thousand years, Mount Athos has been the most significant center of Eastern Orthodox spirituality and education. It represents the cultural heritage of mankind. Mount Athos, the unique monastic country, occupies the unapproachable Athos peninsula in Greece. It is accessible only by boat, over the sea. The same strict rules have been kept for centuries – only men are permitted to visit the territory of Mount Athos. Regarding its importance and influence, Hilandar Monastery ranks the fourth in the hierarchy of all the twenty of Mount Athos monasteries, and its territory is the second largest one. Hilandar Monastery is one of the most important spiritual and cultural centers of the Serbian people. It was founded in 1198, on the remains of the old and abandoned monastery of Helandar, built at the end of the 10th century [12]. The monastery complex Hilandar is a real medieval town within its walls.

Restoration of the Haybarn Complex, within Hilandar Monastery, in order to increase their energy efficiency

The Haybarn Complex is situated near the access road to Hilandar Monastery. It was once used to shelter monastery animals and their food (hay). These buildings were built in the first part of the 19th century, outside the monastery walls but close to them. The Haybarn Complex had not been used for decades, therefore the buildings were partially demolished.

The Haybarn Complex, fig. 1(a), before the 2006 restoration used to consist of [13]:
– a building for keeping mules – the Stable,
– a building for people taking care of those mules (they were called mulekeepers); thus the name of the building – the Mulekeepers' House, and
– a huge building for hay, which used to be called the Haybarn, thus the name for the entire complex.


(a) (b) (c)

Figure 1. The Haybarn Complex: Mulekeepers'House, Stable, Haybarn (left to right); (a) former appearance, (b) façade after the restoration, (c) interior of Stable after the restoration *(photos taken by authors)*

Modern trends in social development increased the number of interested pilgrims and admirers all over the world. They wanted to visit this unique monastic country [14]. Even before the devastating fire of 2004, when a part of the monastery complex Hilandar inside the walls was burnt down, there was a great problem with providing accommodation for both visitors and monastery workers. Since new accommodation capacities were needed, the restoration project for the Haybarn Complex* was launched. The restoration took place in 2005 and 2006.

The objective of the restoration project of the Haybarn Complex was keeping all undamaged parts of buildings, removing all demolished parts and rebuilding all damaged walls using stone, since it is authentic material. Specific construction methods were applied for each restored building. These constructional interventions were carried out in accordance with the conservation requirements: all stone façades, roof structures, and roof covering remained unchanged, as well as the appearance of the building itself. All construction methods and materials used for restoration in order to increase energy efficiency of these buildings are reversible procedures. In other words, these buildings can always be returned to their original appearance, without causing damage.

Results

This paper deals with the analyses of three buildings belonging to the Haybarn Complex – Stable, Mulekeepers' House, and Haybarn, (figs. 1 and 2) in terms of their energy efficiency, through comparison of relevant parameters included in three cases:
- the first case – the buildings prior to restoration (the first half of the 19th century till 2005), fig. 1(a),
- the second case – the current condition of restored buildings (restoration was carried out in 2005 and 2006), figs. 1(b) and (c), and
- the third case – suggestions for improvements on restored buildings.

Energy refurbishment study was applied in order to test these buildings for their energy performance [15] in accordance with the Regulations on Energy Efficiency of Buildings [5].

Restoration of the Stable

The former Stable is a single-storey building, with façade and perimeter walls made of stone (case 1). It used to be connected to the ground floor of the Mulekeepers' House and it was a unique space for keeping monastery animals. Considering the former appearance of this building, fig. 1(a) and its original function, it is not feasible to perform a categorization in terms of energy class, in accordance with the current rules and Regulations on Energy Efficiency. If this building had been used for providing accommodation for people, along with applying hygiene measures only, it would not have met the requirements of the current Regulations on Energy Efficiency of Buildings (tab. 1, case 1).

After the restoration that was performed in 2006, (case 2), the façade walls remained unchanged – both exterior and interior walls had visible stone, figs. 1(b) and (c). The floor was restored and improved by adding thermal insulation. This restoration is very significant because the unique roof structure of this building – king post truss, was kept as it had been before the restoration. The roof structure is a part of the interior in the sleeping rooms for visitors, fig. 1(c). New layers of roof with thermal insulation were installed over the existing roof structure. Small windows arrangement remained on the façade. Roof dormers were put in the same place as they used to be. This is how the form and authentic appearance of the building itself was preserved. The windows were replaced with new, 9 cm thick, wood-framed, double-

* The main project and implementation plan for restoration of the Haybarn Complex were managed by M. Kovačević, Ph. D., N. Šekularac, Ph. D., S. Tripković, arch., and D. Krivokuća, arch., in 2004 and 2005.

-glazed windows with krypton gas (4 + 12 Kr + 4 mm). The space between two glass panels is filled with krypton, the inert gas that improves thermal performance and reduces energy consumption. The front door was replaced with a new one, made of solid wood. This space remained unchanged after the performed restoration (tab. 1, case 2), but with a new function. The restored building consisted of a spacious guest room, sanitary facilities and laundry. Also, the underfloor heating system was installed.

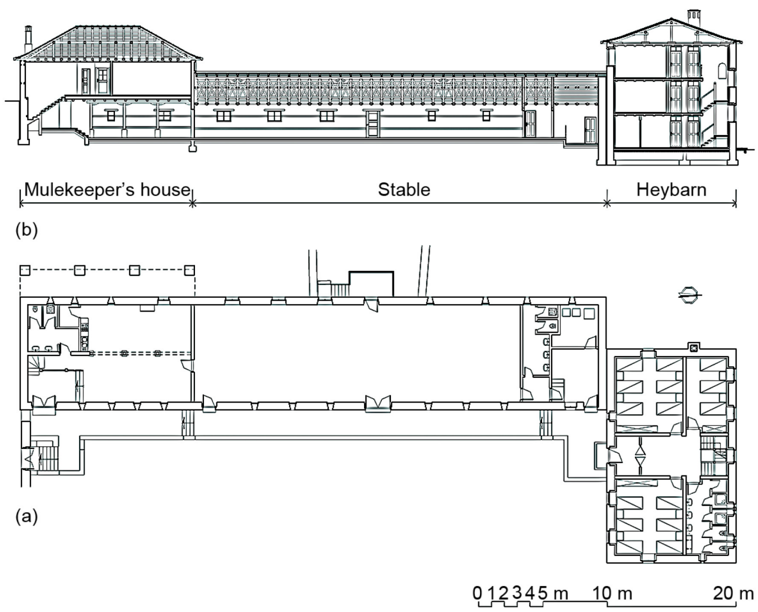


Figure 2. The Haybarn Complex (the appearance after the restoration); (a) ground floor plan, (b) cross-section

In order to conduct a research, this paper dealt with the suggestions about refurbishment and upgrading of the mentioned building in accordance with maximum potentials of this restoration (case 3), without major interventions. It was planned to add thermal insulation to the existing roof structure and replace the existing windows with new, wood-framed, 11 cm wide, triple glazed windows with xenon gas (4 + 8Xe + 4 + 8Xe + 4 mm), in order to increase energy efficiency and comfort standards of this building (tab. 1, case 3). The space between the three glass panels was filled with xenon, the inert gas that improves thermal performaance and reduces energy consumption.

The implementation of the suggested measures for upgrading the restoration of the Stable in order to increase its energy efficiency (tab. 1, case 3) would reduce specific heating energy on an annual basis for 102,18 kWh/m², *i. e.* 23%, in comparison to the current condition of the building restored in 2006 (tab. 1, case 2).

Restoration of the Mulekeepers' House

This building consists of a ground floor and first floor. The ground floor used to be connected to the Stable. It was a space meant for the monastery animals. The first floor accommodated the people taking care of those mules. Exterior walls were made of broken and roughly dressed stone [13]. All the perimeter walls on the ground floor were visible stone walls (case 1). All the upstairs inside walls were plastered. Former windows were single pane windows, single-glazed, and made of wood. If this building had been used to provide accommodation for people, along with the application of hygiene measures only (tab. 2, case 1), it would not have met the requirements of the current Regulations of Energy Efficiency of Buildings.

During the restoration of the Mulekeepers' House in 2006, the visual appearance of its façades remained the same (case 2) – the face of exterior walls were made of stone, as well as interior ground floor walls. Since the upstairs façade stone walls had been plastered before the restoration, the room walls were thermally insulated from the inside during the reconstruction (tab. 2, case 2). As for the ground floor, its floor was restored and insulated. In accordance with the Restoration Plan, the joists as structural components between the storeys remained, along with the wood flooring, as a final coat. However, new fillings were applied. Thermal insulating sheathing boards were installed above the first floor, towards the attic area. Roofing stone plates, as roof covering, was installed in accordance with all modern principles of ventilated roofing. This modern technological design of ventilated roofing and stone as a final roof covering was applied for the first time in conservation and restoration practice, during the restoration of Hilandar Monastery buildings [16]. The windows were replaced with new, wood-framed, 9 cm thick, double-glazed windows with krypton gas (4 + 12Kr + 4 mm). The front door was replaced with a new one, made of solid wood.

After the restoration, the ground floor of the Mulekeepers' House is the space used for receiving guests and sitting, along with a kitchenette and a sanitary block. The upstairs rooms consist of a small room for sitting, three bedrooms and a sanitary block. Underfloor heating was installed on the ground floor and low-temperature heating systems (radiators) were installed upstairs.

The proposal for upgrading the mentioned restored building was done for the purpose of this research (case 3). In order to increase energy efficiency and comfort conditions, the following construction procedures were planned: thermal insulation was installed in the attic area over the existing layers of the attic floor (tab. 2, case 3), and the windows were replaced with new, wood-framed, 11 cm thick, triple-glazed windows filled with xenon gas (4 + 8Xe + 4 + 8Xe + 4 mm).

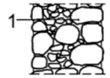
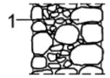
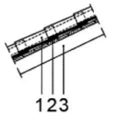
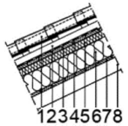
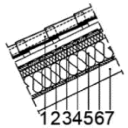
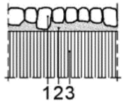
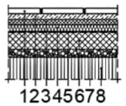
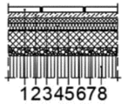
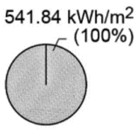
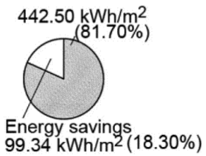
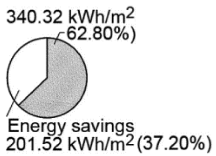
The implementation of the suggested measures for upgrading the restored Mulekeepers' House in order to increase its energy efficiency (tab. 2, case 3), would reduce specific heating energy on an annual basis for 27,66 kWh/m^2, *i. e.* 15.9%, in comparison to the current condition of the object restored in 2006 (tab. 2, case 2).

Restoration of the Haybarn

The Haybarn used to be a tall building used to store hay (case 1). Its perimeter walls were extremely tall and made of broken and roughly dressed stone. The façade stone was also visible, fig. 1(a). The function and original visual appearance of this building cannot be categorized in accordance with current regulations. If this building had been used to accommodate people, including the application of hygiene measures only (tab. 3, case 1), it would not have met the requirements of the current Regulations on Energy Efficiency of Buildings.

The restoration divided this space horizontally into three levels by installing two intermediate floors (case 2). Thermal insulation was applied inside the building on the façade walls. As for the ground floor, the floor was restored and insulated (tab. 3, case 2). Thermal insulation was applied above the last level, towards the attic, between the joists. The wood-framed windows, 9 cm thick, double-glazed (4 + 12Kr + 4 mm) and filled with krypton gas

Table 1. Comparative review of upgrading the sheathing elements in terms of thermal protection and heating energy reduction on an annual basis, for all three analyzed cases of the Stable

	Case 1		Case 2		Case 3	
Façade wall $U_{max} = 0.40$ W/m^{2}K		1. Stone wall 60.0 cm		1. Stone wall 60.0 cm		1. Stone wall 60.0 cm
U [Wm^{-2}K^{-1}]	1.912		1.912		1.912	
Roof $U_{max} = 0.20$ W/m^{2}K		1. Ridge tiles 2. Wood deckling 2.2 cm 3. Rafter-timber construction		1. Ridge tiles 2. Air layer 3. Waterproofing 4. Wood deckling 2.2 cm 5. Air layer 6. Thermal insulation polystyrene 15.0 cm 7. Wood ceiling 2.2 cm 8. Rafter-timber construction		1. Ridge tiles 2. Air layer 3. Waterproofing 4. Wood deckling 2.2 cm 5. Thermal insulation polystyrene (5 + 15) 15.0 cm 6. Wood ceiling 2.2 cm 7. Rafter-timber construction
U [Wm^{-2}K^{-1}]	1.930		0.192		0.155	
Ground floor $U_{max} = 0.40$ W/m^{2}K		1. Pavin stone 10.0 cm 2. Sand 5.0 cm 3. Ground		1. Brick 4.0 cm 2. Mortar 4.0 cm 3. Concrete 4.0 cm 4. Thermal insulation polystyrene 5.0 cm 5. Waterproofing 6. Concrete 12.0 cm 7. Gravel 6.0 cm 8. Ground		1. Brick 4.0 cm 2. Mortar 4.0 cm 3. Concrete 4.0 cm 4. Thermal insulation polystyrene 5.0 cm 5. Waterproofing 6. Concrete 12.0 cm 7. Gravel 6.0 cm 8. Ground
U [Wm^{-2}K^{-1}]	1.632		0.435		0.435	
Specific heating energy demand per year [kWhm^{-2} per year]	541.84		442.50		340.32	
Energy class	G		G		G	
Specific heating energy demand per year/energy savings [kWhm^{-2} per year (%)]						

were installed. The front door was replaced with a new one, made of solid wood. The original visual appearance of the building itself remained the same after the restoration, in terms of building materials, stone façade walls with wooden frames and roof clover along with the same height, form and roof shape, fig. 1(b). Traditional radiator heating system was installed on both ground floor and upper floors of the building. The function of the building is dormitory for visitors. After the restoration, the building consists of three levels – sleeping rooms and sanitary blocks.

For the purpose of this research, the proposal for upgrading the restored building Haybarn was done (case 3) and the following construction procedures were applied: thermal insulation in the attic area over the existing layers of the attic floor (tab. 3, case 3) and new wood-framed windows, 11 cm thick, triple-glazed (4 + 8Xe + 4 + 8Xe + 4 mm) filled with xenon gas.

The implementation of the above suggested measures for upgrading the restored Haybarn to increase its energy efficiency (tab. 3, case 3), would reduce specific heating energy on an annual basis for 3,18 kWh/m², *i. e.* 4,4% in comparison to the current condition of the building restored in 2006 (tab. 3, case 2).

Proposal for energy efficiency increase during the restoration of historic buildings, for the purpose of their re-use

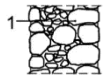
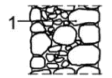
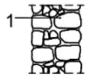
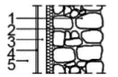
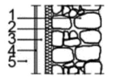
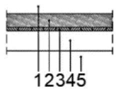
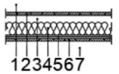
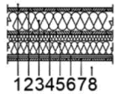
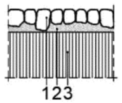
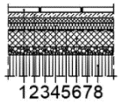
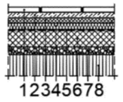
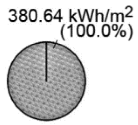
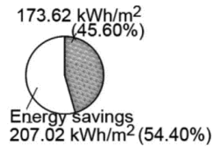
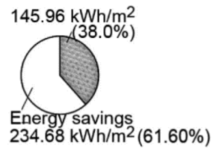
The following energy efficiency measures were applied in order to realize energy refurbishment of historic buildings:
- thermal insulation of the façade walls where it was possible, but only internally,
- thermal insulation of the floors on the ground,
- thermal insulation of intermediate floors, towards the unheated attic,
- thermal insulation of the roof above the attic area,
- replacement of façade joinery (windows and front door),
- new heating system, and
- energy management.

Considering the original visual appearance of a historic building, its architectural style and form, in accordance with the current conservation requirements, it is not allowed to implement standard thermal insulations measures, *i. e.* external wall insulation.

As for the above mentioned cases of internally insulated façade walls, it was necessary to pay special attention to additional fire protection measures and potential defects in terms of: cold bridge (thermal bridge) and water vapor diffusion (condensation). All these construction measures included in the restoration were applied in order to increase energy performance of the buildings for at least one energy efficiency class, which was in accordance with the current thermal regulations.

In order to improve energy saving, it is necessary to develop energy management in this isolated site and start the realization of an energy efficiency improvement plan. Along with the overview of the building condition assessment and selection of methods for improving thermal performances of buildings, it is also important to upgrade the heating system, since it is one of the main conditions for energy efficiency improvement. However, it is crucial to protect ecological values of Mount Athos during these procedures. Heating is delivered through radiators and warm water underfloor heating system. Wood-fired boilers are used for heating. Wood is a renewable source of energy. This energy source is the product of forest thinning (tree thinning and pruning) that is carried out in the area surrounding the monastery

Table 2. Comparative review of upgrading the sheathing elements in terms of thermal protection and heating energy reduction on an annual basis, for the analyzed cases of the Mulekeepers' House

	Case 1		Case 2		Case 3	
Façade wall on the ground floor U_{max} = 0.40 W/m²K		1. Stone wall 60.0 cm		1. Stone wall 60.0 cm		1. Stone wall 60.0 cm
U [W/m²K]	1.912		1.912		1.912	
Façade wall on the first floor U_{max} = 0.40 W/m²K		1. Stone wall 40.0 cm		1. Stone wall 40.0 cm; 2. Thermal insulation polystyrene 5.0 cm; 3. Brick 6.5 cm; 4. Mortar coating 1.5 cm; 5. Heated spac		1. Stone wall 40.0 cm; 2. Thermal insulation polystyrene 5.0 cm; 3. Brick 6.5 cm; 4. Mortar coating 1.5 cm; 5. Heated spac
U [Wm^{-2}K^{-1}]	2.467		0.517		0.517	
Attic floor U_{max} = 0.40 W/m²K		1. Attic area; 2. Mud layer 10.0 cm; 3. Wood decking 2.5 cm; 4. Timber construction; 5. Heated space		1. Attic area; 2. Wood decking 2.5 cm; 3. Air layer 5.0 cm timber construction; 4. Thermal insulation polystyrene 10.0 cm; 5. Gypsum boards 2.5 cm; 6. Wood ceiling 2.0 cm; 7. Heated space		1. Attic area; 2. Wood decking 2.5 cm; 3. Thermal insulation polystyrene 15.0 cm; 4. Wood decking 2.5 cm; 5. Thermal insulation polystyrene (5 + 10) 15.0 cm; 6. Gypsum boards 2.5 cm; 7. Wood ceiling 2.0 cm; 8. Heated space
U [Wm^{-2}K^{-1}]	2.340		0.289		0.107	
Ground floor U_{max} = 0.40 W/m²K		1. Paving stone 10.0 cm; 2. Sand 5.0 cm; 3. Ground		1. Brick 4.0 cm; 2. Mortar 4.0 cm; 3. Concrete 4.0 cm; 4. Thermal insulation polystyrene 5.0 cm; 5. Waterproofing; 6. Concrete 12.0 cm; 7. Gravel 6.0 cm; 8. Ground		1. Brick 4.0 cm; 2. Mortar 4.0 cm; 3. Concrete 4.0 cm; 4. Thermal insulation polystyrene 5.0 cm; 5. Waterproofing; 6. Concrete 12.0 cm; 7. Gravel 6.0 cm; 8. Ground
U [Wm^{-2}K^{-1}]	1.632		0.435		0.435	
Specific heating energy demand per year [kWhm^{-2} per year]	380.64		173.62		145.96	
Energy class	G		E		D	
Specific heating energy demand per year/energy savings [kWhm^{-2} per year (%)]						

property. Since Hilandar Monastery owns large forested areas, all the quantities of wood used for heating are obtained through thinning their own forests. Wood chip boilers are going to be installed in the coming period. Type of heating systems and wood, as an energy source, meet the requirements of environmental protection and gas emission reduction. When wood is obtained by pruning your own trees, it contributes to cost reduction and energy procurement, considering the fact that this is an isolated site and boats are the only means of transport.

Discussion

The interventions of the Haybarn Complex were carried out in accordance with the following principles: to preserve authentic construction and materialization; to keep the original visual appearance as much as possible and wherever it is feasible; to keep and conserve all historical and decorative elements that reflect historical periods of construction and the whole ambient value of the authentic monastery.

Using the analysis and evaluation of these historic buildings, based on the realized restoration situations and suggested energy efficiency measures, the authors managed to obtain the results that have never before been valued in this way. The authors obtained the results about real values and achieved energy saving related to the concrete examples of historic buildings, using thermal protection measures as well as site protection measures, in compliance with all current conservation requirements in the field of restoration.

This paper presents the solutions to energy refurbishment and/or energy retrofit of historic buildings in case studies.

The hypothesis was tested by on-site assessment and valorization of each building belonging to the Haybarn Complex, in accordance with energy efficiency test models, in all three cases. The obtained results fully support the hypothesis on potential energy saving and energy efficiency increase during the restoration of historic buildings, along with the implementation of appropriate construction procedures and preservation of the original visual appearance of buildings, in accordance with current conservation requirements. All these measures are applied in order to carry out restoration and re-use of historic buildings, without negative effects on protected sites, such as Mount Athos.

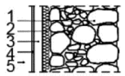
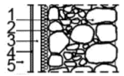
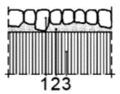
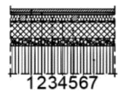
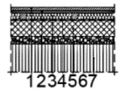
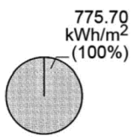
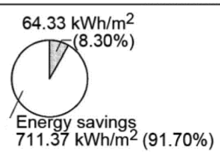
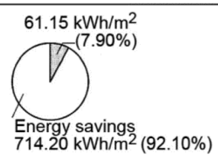
This research led to the same conclusions as the ones made by Hensley and Aguilar [2], regarding the necessity of performing regular maintenance of historic buildings, monitoring the process of restoration and implementing long-term protection measures in order to preserve historic ambient. Also, the research confirms the conclusion made by Turanjanin *et al.* [17] that thermal insulation of the house envelope can reduce heating energy. This paper provides the same conclusions as the ones made by Bionaz [3], regarding the restoration of historic buildings made of massive stone walls – the interventions in terms of windows replacements and curtains are not quite enough to meet the modern requirements of thermal comfort and energy efficiency, unless the additional thermal insulation is installed on all perimeter walls from the inside.

Martins and Carlos [11] held the view that heritage of a buildings is preserved if retrofitting is primarily carried out in the interior of the building, maintaining all of its original exterior wall aspects. Therefore, their opinion has been confirmed.

The research was directly tested and assessed through practical application on a secluded and ecologically valuable site of Mount Athos, which represents its greatest contribution.

Further research in this field will deal with energy efficiency of the Haybarn Complex, if some large-scale restoration projects as well as extensive construction works are to be

Table 3. Comparative review of upgrading the sheathing elements in terms of thermal protection and heating energy reduction on an annual basis, in the analyzed cases of the Haybarn

	Case 1		Case 2		Case 3	
Façade wall $U_{max} = 0.40$ W/m^{2}K		1. Stone wall 60.0 cm		1. Stone wall 60.0 cm 2. Thermal insulation polystyrene 5.0 cm 3. Brick 6.5 cm 4. Mortar coating 1.5 cm 5. Heated space		1. Stone wall 60.0 cm 2. Thermal insulation poly-styrene 5.0 cm 3. Brick 6.5 cm 4. Mortar coating 1.5 cm 5. Heated space
U [Wm^{-2}K^{-1}]	1.912		0.478		0.478	
Roof/Attic area $U_{max} = 0.40$ W/m^{2}K		1. Stone slabs in mortar 12.0 cm; 2. Wood decking 2.5 cm; 3. Rafter-timber construction; 4. Interior		1. Attic area; 2. Wood decking 2.5 cm; 3. Air layer 5.0 cm; timber construction; 4. Thermal insula-tion polystyrene 10.0 cm; 5. Gyp-sum boards 2.5 cm; 6. Timber construction; 7. Heated space		1. Attic area 2.5 cm; 2. Wood decking 2.5 cm; 3. Thermal insulation poly-styrene 15.0 cm; 4. Wood decking 2.5 cm; 5. Thermal insulation polystyrene (5 + 10) 15.0 cm; 6. Gypsum boards 2 × 1.25 2.5 cm; 7. Timber construction; 8. Heated space
U [Wm^{-2}K^{-1}]	2.490		0.301		0.109	
Ground floor $U_{max} = 0.40$ W/m^{2}K		1. Pavin stone 10.0 cm; 2. Sand 50 cm; 3. Ground		1. Decking 2.2 cm; 2. Plywood 2.2 cm; 3. Thermal insulation polysty-rene 5.0 cm; 4. Waterproofing; 6. Concrete 12.0 cm; 7. Gravel 6.0 cm; 8. Ground		1. Decking 2.2 cm; 2. Ply-wood 2.2 cm; 3. Thermal insulation polystyrene 5.0 cm; 4. Waterproofing; 6. Concrete 12.0 cm; 7. Grav-el 6.0 cm; 8. Ground
U [Wm^{-2}K^{-1}]	1.632		0.397		0.397	
Specific heating energy demand per year [kWhm^{-2} per year]	775.70		64.33		61.15	
Energy class	G		C		C	
Specific heating energy demand per year/energy savings [kWhm^{-2} per year (%)]						

performed. The construction works would include additional insulation to already restored and thermally isolated interior walls, as well as casing and plastering of the walls. This is the way to analyze the undertaken refurbishment measures in order to see which one of them could enhance the energy class of buildings, thus turning them into energy efficient buildings.

Conclusions

The need to accommodate the increasing number of visitors of Hilandar Monastery shaped the restoration and refurbishment of demolished buildings included in the Haybarn Complex, turning them into the rooms used for accommodation. In this way, the Haybarn Complex created the connection between cultural heritage and modern social changes.

The restoration of a listed building requires the following energy efficiency measures:

– detailed and carefully planned site analysis,
– restoration level and type,
– energy refurbishment and/or energy retrofitting measures to be taken in order to provide reusability of that space in accordance with the current conservation requirements, and
– establish an energy management system for isolated site of Mount Athos, in order to increase energy saving and energy efficiency.

It can be concluded that the process of design and restoration of listed buildings, using appropriate energy efficiency measures, is reversible and implies individual approach regarding each historic building. In order to achieve energy saving and thermal loss reduction it is necessary to install thermal insulation coatings, in accordance with the current conservation requirements, since it is the only way to increase the level of energy efficiency of a historic building. All the implemented measures of energy refurbishment and/or energy retrofitting were carried out in compliance with technical and ethical conservation requirements. The main contribution of the paper is a practical assessment of the achieved results on energy refurbishment and re-usability potentials, using the energy efficiency principles and measures and keeping the authentic appearance during the restoration of listed buildings.

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